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A Research on Hybrid Planning to Enhance Watershed Management in Addressing Urbanization

（都市化地域における強い流域管理のためのハイブリッド計画に関する研究）

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An Institutional Model Validated through a Detailed Investigation from the Shawsheen Watershed, USA

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–米国シャシーン流域における詳細調査を通じて検証された制度モデル）

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ABSTRACT

Urbanization refers to the process of converting natural land into impervious areas that support urban life. Farmlands, wetlands, forests, and deserts have been transformed into human settlements. The man-made urban landscaping such as buildings, roads, parking lots, lawns, and parks, have caused substantial changes to the natural water environment, rivers and watershed systems. In general, urbanization increases the prevalence in flooding, water quality impairments, stream morphological instability, groundwater deficits, and degradation to aquatic life and essential habitats. Generally, these effects are considered local environmental issues. The impacts, multidisciplinary in nature, are inter related and require an interdisciplinary approach to effectively accomplish sustainable watershed management. It also requires external resources, generally obtained from government, academic, and donor agencies, to address multi-disciplinary local issues through local decision making by including all stakeholders.

Watershed management has witnessed several paradigm shifts over the last several decades. Traditionally, the management of watershed follows a top-down approach, in which the governments drive the process to meet national goals and extend downward to provincial/state and local levels in a top-down manner. Such approaches are subject to common criticisms such as lack of local input and insufficiency in addressing multidisciplinary challenges accustomed to local conditions. The bottom-up approach emerges as part of the efforts to overcome the known limitations of the top-down approach, specifically fulfilling the limitation of local input. While attempts to provide the missing local knowledge and involvement, the bottom-up approach is also criticized for issues such as symbolic engagement, oversimplification of the diversity of communities, capacity limitation, etc. The third paradigm, which is a combination of both the top-down approach and the bottom-up approach, has emerged only recently in watershed management. With the realization that neither approach effectively addresses watershed management issues single-handedly, the hybrid approach tries to effectively integrate the advantages of the two approaches while overcoming their respective limitations. Despite the positive conceptual recognition, there is little or no real-world application on how the hybrid approach could potentially help addressing urbanization.

The overall goal of this research is to propose a theoretical framework (theory) and validate a hybrid and self-sustaining watershed management framework in a practical set up for mitigating urbanization impacts (practice), which will eventually lead to a practical institutional model

(policy) that can be readily implemented in different watersheds. Towards reaching the goal, the research identified three objectives.

The first objective of this research is to develop a new management framework (theoretical) that can overcome the limitations of both top-down and bottom-up approaches and to provide a self-sustaining institutional structure for interdisciplinary decision making at watershed level. To meet this objective, detailed literature reviews were conducted to gain understandings of the strengths and weaknesses of top-down, bottom-up, and hybrid approaches employed in watershed management with specific focus on addressing issues associated with urbanization. Four international cases representing the top-down approach and another four cases representing the bottom-up approach were identified from scholarly literature published in peer reviewed journals and books. A Strength, Weakness, Opportunity, and Treat (SWOT) analysis were carried out on all eight cases. The new management framework was formulated by integrating the identified strengths while excluding identified weaknesses or major causes of weaknesses. The new framework consists of three major elements: common platform, partnership, and facilitation designed to integrate the strengths of both top-down and bottom-up approaches and to provide a set of necessary conditions for a self-sustaining model for an interdisciplinary approach at the local or grass-roots level. With effective integration of the governmental agencies and institutions at the top with the local residents and non-governmental organizations at the bottom, the hypothesis is that the hybrid approach that fully accepts or considers interdisciplinary thinking in every step of decision making, can serve as a self-sustaining model in achieving effective management of addressing urbanization impacts.

The second objective of this research is to validate the theoretical new management framework through a practical real-world application to address water resource impacts related to urbanization using an interdisciplinary approach while also further investigating necessary mechanisms for a sustainable decision making process. The process for selecting the validation case involved the review and evaluation of four candidate watersheds located in the eastern United States, with similar climate and development conditions, and for which watershed management plans to address urbanization issues were developed. The candidate watersheds were identified from a review of published watershed management related project reports. The evaluation comprised conducting a baseline analysis to compare these cases within the context of identifying the best case for validating the theoretical framework through a practical application in a real-world setting. The cases were evaluated for the presence of major elements and the necessary conditions identified in the theoretical framework and on each case's suitability for a detailed investigation and gaining knowledge. Also, an examination of environmental quality improvements resulting from related watershed planning and implementation activities was conducted. Ultimately, the Shawsheen watershed, Massachusetts, USA case was selected because of its high compatibility with the theoretical framework especially the systematic decision-making process that led to actual environmental improvement in the watershed. Finally, the new framework was validated using the Shawsheen watershed case and was evaluated in great detail for its capacity in mitigating adverse urbanization impacts. For this purpose numerous sources of information/documentation were consulted including published articles, technical reports, meeting minutes/notes, and the notes from in person meetings and phone conversations.

During the detailed investigation, it was confirmed the existence of the characteristics of the major components in Shawsheen that was entirely consistent with the new framework. Common platform was to convene and conduct the watershed management at the local level by integrating the input from the government agencies, typical top-down players, and NGOs and local partners, typical bottom-up players. It was very clear that the platform was used for careful deliberation and for sharing information and results of technical analysis which resulted in well-informed decision making. The other component was the established partnership of two major stakeholder groups. The first group was composed of private residents, environmental stewards, watershed groups and non-governmental organizations, the key group that drives the bottom-up management. The second group was composed of government representatives, who are often responsible to implement and enforce regulations, typically through top-down management. Simultaneous participation of these groups in addressing these identified issues greatly improved the atmosphere for constructive dialogues. Although the two groups have different motivations, they shared the same goal of problem solving for watershed protection and restoration which allowed them to build a sustainable partnership under the new management framework. The bonding agent of the partnership was the facilitation through quarterly meetings, and the systematic interdisciplinary decision making process in addressing urbanization issues at the Shawsheen. The characteristics of the new framework at the Shawsheen River Watershed highlighted the benefits from an interdisciplinary management approach, in which scientific analysis played a critical role in all aspects of the process, especially for resolving conflicts, confusions and concerns among stakeholders and helping them to move toward agreements.

An innovative planning approach was born as a solution to a complex and unknown (confusion) situation in decision making and includes resolution to stakeholder confusion through deliberation among all stakeholders as a practical implementation step within the existing regulatory programs. The approach, using hydrology as surrogate, proved to be effective in managing watersheds that are faced with urbanization impacts but at the same time are bounded by limited data and technical capabilities. Instead of going through the traditional tedious and expensive processes of data collection, analysis, model development, and control measure assessment, this new planning approach provided a simple yet reliable alternative for effective watershed management. The power of the approach was fully utilized through the new management framework, in which the scientific findings successfully supported informed decision making that involved all stakeholders. More importantly, the water quality data and the hydrological information recently reported revealed that the environmental quality is improving due to the application of the plans developed through the implementation of the framework.

The third and final objective of this research is to further enhance the framework with lessons learned from its application in the Shawsheen. That is to produce a self-sustaining institutional structure for interdisciplinary decision making at the watershed level (policy). More specifically to make further refinements based on real-world lessons learned from an actual application (practice) of the new management framework. The refined management framework (policy), Grass-root Watershed Management (GWAM) Model, is intended to serve as a generic institutional model for holistic urbanization impact mitigation. Therefore, an analysis was done to link the theoretical management framework into a policy tool using the lessons learned and practical knowledge gained in the Shawsheen application. The lessons learned related primarily to capacity building at the watershed level and thus, the framework was refined accordingly to enhance organizational and functional capacities by providing the necessary mechanisms to sustain these capacities at the watershed level. The organizational capacity consists of a structure (three elements), a process (long and short-term planning), and a set of necessary conditions to conduct the function of addressing urbanization issues through an interdisciplinary approach in a self-sustaining structure. The functional capacity includes a set of systematic steps (problem identification, problem recognition, problem investigation for implementation planning, and problem solving through implementing actions) that integrates science into decision making as an essential mechanism to sustain the process. The GWAM model represents the first hybrid model that has been specifically designed and field verified for mitigating urbanization impacts in watershed management at the watershed level.

要　旨

都市化は、自然状態の土地を不透水性の地域に変えてしまう。農地、湿地、森林、砂漠は、人間の居住地へと変化してきた。建物、道路、駐車場、芝生、公園などの人工都市景観は、自然の水環境、河川、流域システムに大きな変化をもたらした。一般的に、都市化は洪水を頻発させ、水質を悪化させ、河川流量の不安定性を増し、地下水を欠乏させ、水生生物の生息地を劣化させる。これらは地域の環境問題と考えられているが全世界に共通する課題でもある。これらの影響を解明し、持続可能な流域管理を効果的に達成するためには、学際的なアプローチが必要である。また、すべての利害関係者を含めた地域の意思決定をめざすために、政府機関、学術機関、ドナー機関といった外部リソースも必要である。

流域管理は、過去数十年間でいくつかのパラダイムシフトを経験してきた。伝統的に、流域管理者はトップダウン方式を採用しており、政府はこの方式を推進して国家レベルの目標を達成し、州レベル、地域レベルにも適用している。このようなアプローチは、地元情報の欠如や、地域の状況に見合った学際的課題対応の不十分さといった批判を受けやすい。一方、ボトムアップ方式は、地域情報を十分に取り込むことで、トップダウン方式の限界を超える。しかしコミュニティの多様性の過度の単純化や能力不足という批判がある。どちらのアプローチも流域管理問題に十分には対処できていないことを認識した上で、ハイブリッド方式は２つのアプローチの利点を効果的に統合しようとする。この考え方は特段新しいものでもないにもかかわらず、都市化地域においてハイブリッド方式が適用されたケースは存在しなかった。

そこで本研究では、ハイブリッド計画の理論的枠組みを提案し、それによって都市化の影響を軽減させることを実践し、自立的な流域管理の枠組みを検証することを最終目標とする。この枠組みは、一般化され、異なった流域にも容易に適用することができるだろう。この最終目標を達成するために、三つの目的を設定した。

第一の目的は、トップダウンとボトムアップの両方のアプローチの限界を克服し、流域レベルでの学際的意思決定のための自立的な制度構造を提供することができる新しい管理フレームワークを開発することである。この目的を達成するために、都市化地域での流域管理で採用されているトップダウン、ボトムアップ、およびハイブリッド方式の

長所と短所に焦点を当てて、詳細な文献レビューを行った。それぞれの既往研究に対して、強み、弱み、機会、および脅威を分析する SWOT 分析を行った。分析によって識別された弱みおよびその原因を除外しながら、識別された長所を統合することによって、新しい管理フレームワークを策定した。この新しいフレームワークは３つの主要な要素で構成されている。すなわち、トップダウンとボトムアップの両方のアプローチの長所を統合し、草の根レベルでの学際的なアプローチに必要な一連の条件を提供するための共通プラットフォーム、パートナーシップ、および円滑化である。上部の政府機関等と下部の地域住民や NGO との効果的な統合により、意思決定のあらゆる段階で、学際的な考え方を考慮したハイブリッド方式が有効であるという仮説が立てられた。これは都市化の影響に対処した効果的な流域管理を達成する自立モデルとなろう。

第二の目的は、学際的で実用的な実際の現場での適用に基づいた、理論的な新しい管理枠組みを検証することである。検証事例を選択するために、同程度の気候条件と都市化状況を持つ米国東部に位置する四つの候補流域を選択した。公開された集水域管理関連のプロジェクト報告書から、ベースライン分析を読み込み、調査内容と得られた知見とを評価した。また、集水域管理計画と実際の活動からもたらされる環境の質の改善も検討した。その結果、米国マサチューセッツ州シャシーン川流域が、適切な理論的枠組みを持ち、流域の環境改善につながる体系的な意思決定プロセスを有していると評価した。このシャシーン川流域において、新しい枠組みを検証し、都市化による悪影響を軽減する能力について詳細に評価した。そのために、出版記事、技術報告書、会議議事録・メモ、そして筆者による会議メモやインタビュー記録など、多数の情報を精査した。

詳細な調査の結果、シャシーン川管理委員会は新しいフレームワークと完全に一致していることが確認された。すなわち、政府機関等の典型的なトップダウン型プレイヤー、NGO や地元のパートナー等の典型的なボトムアップ型プレーヤーからの意見や情報を統合するプラットフォームが形成され、当該地方レベルで集水域管理が行われた。このプラットフォームが慎重な審議と情報・技術分析の結果の共有のために有益であったことは明白だった。もう一つの成果は、二つの主要な利害関係者グループにおいて協調体制が確立していたことである。第一グループは、住民、環境保護委員会、集水域グループ、および非政府組織で構成され、ボトムアップ管理を希求している。 第二グループは政府の代表者で構成され、時にトップダウン管理を通して、規制を実行し実施する責任があ

った。これらの二グループは異なる動機を持っているが、流域の保護と修復という同じ目標を共有しており、新しい管理枠組みの下で持続可能なパートナーシップを築くことを可能にした。シャシーン川流域の新しいフレームワークの特徴は、審議過程における利害関係者間の衝突、混乱、懸念を解消し合意形成を支援するために、正確な科学的分析に基づく学際的管理アプローチを採っていたことである。

この革新的な計画アプローチは、意思決定過程における複雑で未知の混乱状況の解決策として生まれ、すべての利害関係者間の審議による混乱の解決をもたらした。簡単で信頼性の高い水文学的検討も都市化流域での管理に効果的であることが証明された。さらに重要なことは、近年報告された水質および水文学的データは、環境の質が改善されていることを明らかにしている。

第三の目的は、シャシーンから学んだ教訓を使って管理枠組みをさらに強化することである。それは流域レベルでの学際的意思決定のための自立的な制度的構造を作り出すことである（政策）。より具体的には、新しい管理枠組みの現場への適用（実践）から学んだ教訓に基づいてさらに洗練させることである。洗練された管理フレームワーク（政策）、草の根流域管理（GWAM）モデルは、全体的な都市化の影響緩和のための一般的な制度モデルとして機能することを目的としている。そこで、シャシーンで得られた教訓と実践的な知識を用いて、理論管理の枠組みを政策ツールにリンクするための分析が行われた。得られた教訓は、主に流域レベルでの能力開発に関連していたため、流域レベルでこれらの能力を維持するために必要なメカニズムを提供することによって、組織的および機能的能力を強化するための枠組みが改良された。組織的能力は、構造（三要素）、プロセス（長期および短期計画）、そして自立的構造の中で学際的なアプローチを通して都市化問題に対処する機能を果たすために必要な条件のセットから成る。機能的能力は、プロセスを維持するための不可欠なメカニズムとして自然科学を意思決定に統合する一連の体系的なステップ（問題識別、問題認識、実装計画のための問題調査、および問題解決を含む）を含んでいる。結論として、本研究で提案する GWAM モデルは、都市化の影響を軽減するために構築され、現場で検証された最初のハイブリッドモデルである。

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1.0 INTRODUCTION

1.1 HISTORICAL PROSPECT OF WATER MANAGEMENT

Water is essential for all living organisms on the earth in some form. Therefore, it influences population growth, development, human health, living conditions, biodiversity and atmospheric dynamics and climate conditions. Water management has been a part of human life for thousands of years as human populations have controlled the natural water flow and quality to meet various needs. Along with the development of human civilization, the challenges in water management also continue to evolve. Despite the long history in water use and water management, humans have made little or no success in managing water well. The developed countries faced rapid economic development in the nineteenth and twentieth centuries and the developing countries are facing rapid development in the twentieth and the twenty-first centuries. Often these developments come at the expense of sound water management. Introduction of technologies, such as irrigation systems, water and wastewater treatment and supply systems, hydro-power reservoirs, and flood control measures, have ignored their environmental consequences. Substantial water quantity, quality and pollution issues around the world became inevitable consequences of development and it resulted in worldwide actions to address the issues.

The United Nations (UN) Conference on Human Environment, Stockholm, Sweden in 1972 was the first turning point for recognizing the issue. The conference declared, “A point has been reached in history when we must shape our actions throughout the world with a more prudent care for their environmental consequences.” At the same time, individual countries also have started intensive regulatory efforts to control water pollution, for example the Clean Water Act (Public Law 92-500, October 18, 1972) in the USA and Water Disposal and Public Cleansing Law and Water Pollution Control Law in Japan in 1970s (JETRO, 2006). The UN Conference on Water at Mar del Plata, Argentina in 1977 was viewed as a landmark event in water management. An action plan was developed with recommendations targeted at meeting the goal of safe drinking water and sanitation for all settlements by 1990. The action plan also emphasized a strong, centralized, and national commitment to water management. Despite the formal and global reorganization and global consensus at Mar del Plata, the issues that intended to address remained significant even after 15 years as reported by Lee (1992) during the UN Conference on Environment and Development held in Rio de Janeiro in June 1992. The Rio meeting helped to examine and understand the drawbacks in water management and to recognize the need for careful, strategic water management. It was emphasized that over centralization of water management had failed and must be replaced with locally responsive systems at the watershed level (Lee, 1992; Koudstaal et al., 1992). Since then the concept of watershed-based management has been an integral part of water management. 1st World Water Forum (WWF), Marrakech in 1997, 2nd WWF, Hague in 2000, World Summit on Sustainable Development, Rio+10, in Johannesburg in 2002, 3rd WWF, Japan in 2003, 4th WWF in Mexico in 2006, 5th WWF in Turkey in 2009, 6th WWF in France in 2012, 7th WWF in Republic of Korea in 2015 and 8th WWF in Brazil in March 2018 have made it clear that sustainable water management is everybody's business. Recently adopted resolution, on Sustainable Development Goals on September 15, 2015 at the United Nations in New York, USA, includes several references to water governance and stakeholder engagement through not only a dedicated goal on water (No. 6) and a target on local participation, but also other governance-related goals referring to inclusiveness, gender equality, capacity building, policy coherence, multi-stakeholder partnerships, data, monitoring and accountability (Akhmouch and Clavreul, 2016). It is clear that a strong recognition exists to institute water management by engaging all stakeholders in the watershed.

1.2 WATERSHED PLANNING AND MANAGEMENT

Nowadays watershed-based planning and management has become an effective way, in some instances the only way, to deal with the issues that threaten the local, regional, and global water environment. It has also become a social aspect all over the world (Lant, 1999; Griffin, 1999; Ewing, 1999; Porto et al., 1999) and watersheds are being implemented as jurisdiction boundaries (Pyle et al., 2001). Especially, it is very effective in issues associated with development and land use change as these issues require collaboration, commitment, and continuation (3C) approach of stakeholders who live in the watershed. The overall goal of watershed planning and management is to balance the socio-economic goals and environmental goals within the healthy ecosystem context. Ideally, a watershed management framework allows future development to accommodate population growth while minimizing negative impacts of land use activities on surface waters and other environmental assets.

Watershed management has witnessed several paradigm shifts over the last several decades. Traditionally, the management of watershed follows a top-down approach, in which uniform sets of structures, roles, and programs that are formulated at high levels to meet national goals and extend downward to provincial/state and local levels in a top-down manner. Such approaches, while proven effective in implementing certain regulations and practices, were also subject to common criticisms such as lack of local input and insufficiency in addressing multidisciplinary challenges accustomed to local conditions. The bottom-up approach emerged about three decades ago as part of the efforts to overcome the known limitations of the top-down approach, specifically fulfilling the limitation of local input in planning and decision making processes of watershed management in addressing multidisciplinary challenges. As effective as the bottom-up approach in addressing the “overarching” issues of the top-down approach, the bottom-up approach is also criticized for issues such as tokenism (symbolic participation), overlooking the diversity of community, capacity limitation, etc. The third paradigm, which is a combination of both the top-down approach and the bottom-up approach, emerges only recently in watershed management. With the realization that neither approach can effectively address the myriad of watershed management issues single-handedly, the hybrid approach tries to effectively integrate the advantages of the two approaches while overcoming their respective limitations. It is important to note that the recently adopted policy statement, Policy Statement 422 – Watershed Management, of American Society of Civil Engineers (ASCE), includes the same fundamental of integrating government policies and programs with cooperative stakeholder partnership for sustainable watershed based water management (ASCE, 2018).

Despite the recognition of substantial benefits that the hybrid approach could bring success to watershed management, most studies on the hybrid approach are limited to conceptualization and there are a few actual case studies that attempted to address the hybrid approach in watershed management. Specifically, no case studies have been found in the literature investigating how the hybrid approach could potentially help addressing urbanization effects since the hybrid approach is relatively new. Also, the multidisciplinary nature of urbanization related issues requires many elements, from top-down to bottom-up and vise-versa, for which very little knowledge exists in literature regarding the linkages to each other. The urbanization process exerts negative multidisciplinary impacts on the integrity of site specific natural watershed conditions in multiple scales, such as small tributaries to large river systems. These impacts are best analyzed and addressed with local inputs, as many of these are site specific and require consistent local monitoring along with appropriate policies and regulations from conventional governance in an interdisciplinary platform. The challenge in effective watershed management at local level is how to bring needed external resources, generally from government, academic, and donor agencies, to address multi-disciplinary local issues through local decision making by including all stakeholders. However, there is limited knowledge on how a functional institutional model can be established for effective watershed management.

1.3 OVERVIEW ON THIS RESEARCH

The overall goal of this research is to propose a theoretical framework (theory) and validate a hybrid and self-sustaining watershed management framework in a practical set up for mitigating urbanization impacts (practice), which will eventually lead to a practical institutional model (policy) that can be readily implemented in different watersheds. With effective integration of the governmental agencies and institutes at the top and the local residents and non-governmental organizations at the bottom, the hypothesis is, that fully taking the consideration of interdisciplinary thinking in every step of decision making, can serve as a self-sustaining model in achieving effective management of urbanization impacts.

As a hybrid approach, a new management framework is formulated by evaluating practical cases in both top-down and bottom-up approaches through baseline analysis and selection of the necessary features by integration of the strengths while eliminating the weakness or major causes for weakness. Also, a set of necessary conditions, identified from literature, for interdisciplinary approach and self-sustaining model, are incorporated into the framework. Then the theoretical framework is further validated through analysis of cases where watershed management plans were developed for addressing challenging urbanization issues, to select a successful case for detail investigation. The Shawsheen watershed in Massachusetts, USA, a successful case, is further investigated to analyze the linkage of three issues; flooding, aquatic life impairment, and bacteria impairment, and address the issues through interdisciplinary approach for better environmental water quality. Also, the process of decision making and the mechanism to sustain such processes are further examined. An analysis is performed, to link the theoretical management framework into a policy tool from the lessons learned from the practical knowledge gained at the Shawsheen, from the prospective of capacity building at watershed level, and then the framework is refined accordingly. Based on the lessons learned, the new management framework was enhanced as a general hybrid model, Grass-root Watershed Management (GWAM) Model with defined structure and processes in place to perform the function of addressing the issues while identifying the mechanism to sustain the structure, processes and function.

1.4 STRUCTURE OF THE THESIS

The thesis is organized in seven chapters, structured (Figure 1-1) to meet the objectives of the research. Chapter 1 introduces and outlines the research. Chapter 2 presents the state of watershed management to address urbanization, and the need for the research through literature review. It investigates the issues associated with urbanization, needs to appropriately address such issues, state of top-down, bottom-up and hybrid watershed managements, and knowledge gaps and needs for a research. As a result, Chapter 2 also defines the goal and the three objectives of the research. Then Chapter 2 presents the research approach/methodology for each objective. Chapter 3 formulates the new management framework that can overcome the limitations of both top-down and bottom up approaches and to provide self-sustaining institutional structure for interdisciplinary decision making at the watershed level. Chapter 4 validates the framework through cases, where watershed management plans were developed for addressing challenging urbanization issues, to select a successful case for detailed investigation. After confirming the selection, Chapter 4 further investigates the decision-making process through the data collected from the successful case, the Shawsheen River Watershed in USA in addressing three major issues associated with urbanization. To better understand the complexity of issues that requires an interdisciplinary approach in decision making, Chapter 5 analyzes urbanization, consequences, decision making, coordinated remedial action and environmental water quality improvement through a detailed investigation at the Hanscom Sub-watershed. It also examines an innovative planning approach in depth that was an outcome of the application of the new framework for the Shawsheen. Chapter 6 enhances the management framework into a general institutional model, **G**rass-root **WA**tershed **M**anagement model (GWAM) for addressing urbanization related watershed issues, including a GWAM framework and the mechanism to sustain it, based on the formulated new management framework (Chapter 3) and the lessons learned (Chapters 4 and 5) from the field implementation from the Shawsheen. Chapter 7 concludes the thesis by summarizing the research, objectives, methodologies/approaches carried out, and the results achieved. Also, it discusses GWAM model's ability with defined structure and processes in place while identifying the mechanism to sustain the structure and processes for effective watershed management, along with the recommendations for future research.

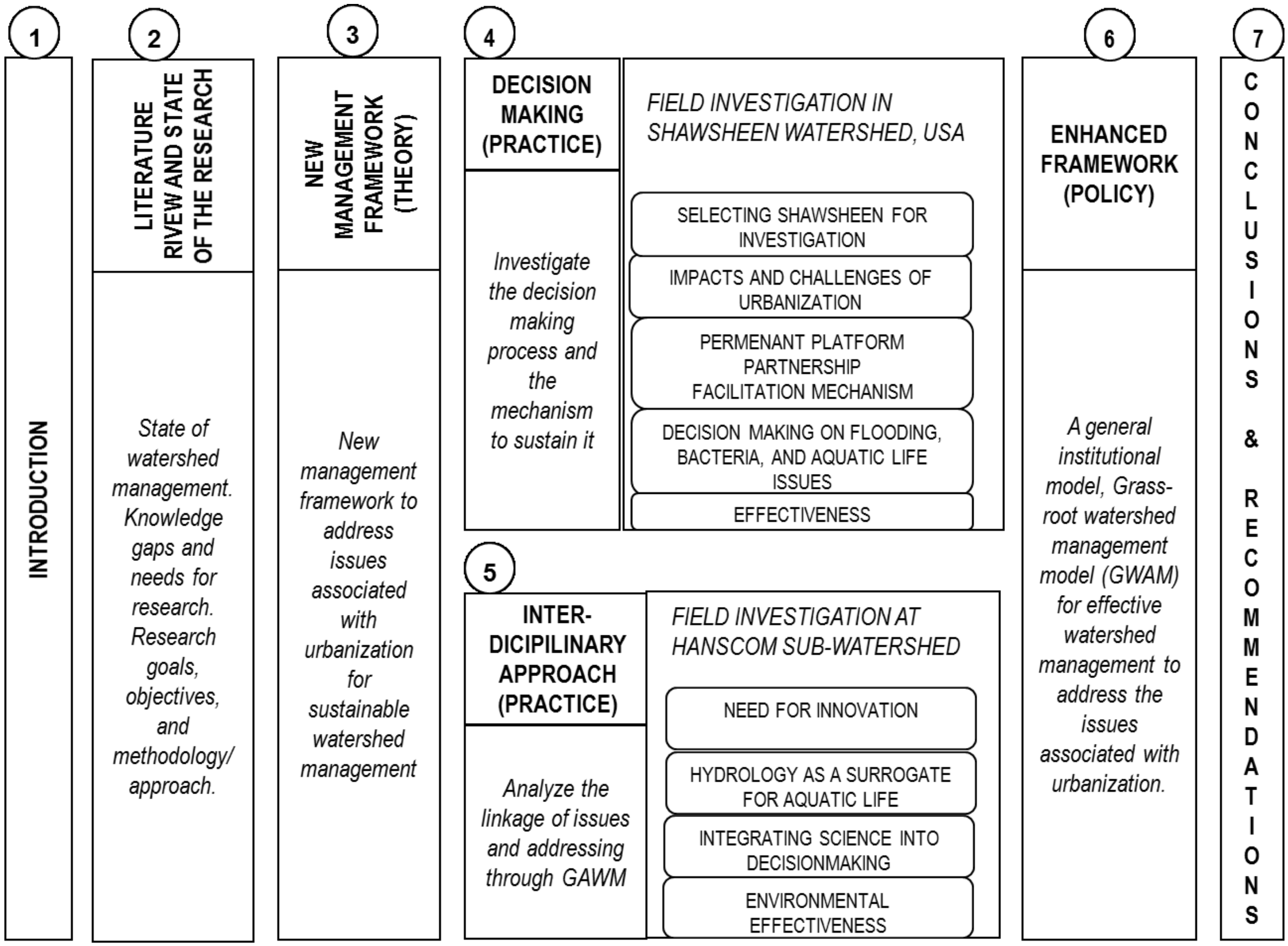

Figure 1-1. Organization of the Thesis. Numbers in the circles represent the chapter number.

2.0 LITERATURE AND STATE OF THE RESEARCH

This Chapter provides an overview on the urbanization and its multidisciplinary impacts. Also, it presents the state of watershed management, top-down, bottom-up and hybrid approaches, to address the urbanization. By clearly evaluating the state of the research, this Chapter identifies the knowledge gap that is to be filled before establishing a functional institutional model for effective watershed management. It leads to defining the goal, objectives and methodology/approach of the research in this Chapter.

2.1 URBANIZATION AND THE MULTIDISCIPLINARY IMPACTS

Urbanization refers to the process of converting natural land into impervious areas that support urban life. Woodlands, wetlands, forests, and deserts have been transformed into human settlements. The man-made urban landscaping such as buildings, roads, parking lots, lawns, and parks, have caused substantial changes to the natural water environment, rivers and watershed systems. Urbanization and its threat to the rivers are well documented problems. Leopold (1968), Hollis (1975), US EPA (1983), Booth (1991), and Quilbe et al. (2008) are among many authors who addressed the impact of urbanization on rivers. In general, urbanization resulted in flooding, water quality impairments, stream morphological instability, groundwater deficits, and aquatic life and habitat degradation. Although these effects are considered local environmental issues, the prevalence of urbanization and its cumulative effects all over the world has global consequences (Foley et al., 2005).

The impacts of urbanization on watershed hydrology have been recognized and documented all over the word (Walling and Gregory, 1970; Williams, 1976; Daamen et al., 2003; Thanapakpawin et al., 2003; DeFries and Eshleman, 2004; Sullivan et al., 2004; Quilbe et al., 2008). In general, changes in urban hydrology occur as a result of increased imperviousness within the watershed. The imperviousness is defined as the sum of roads, parking lots, sidewalks, rooftops, and other impermeable surfaces of the urban landscape. Soil compaction during construction reduces the capacity of soil storage and infiltration into sub-surface and deep groundwater aquifers. Installing drainage systems (gutters, curbs, collection systems and storm drain pipes) increase the rate and volume of runoff from precipitation and the efficiency in which it is delivered to surface waters during rain events. As a result, increased runoff volume (Schuler, 1987) and increased peak discharges to rivers have caused floods (Hollis, 1975; Leopold, 1994; Konrad and Booth, 2002;

Kimaro et al., 2003) and excess bank-full discharges caused channel instability and failures (Leopold, 1968 & 1994; Henshaw and Booth, 2000). Decreased infiltration resulted in decreased baseflow and drought in urban waters (Kelin, 1979; Simmons and Reynold, 1982; Saravanapavan et al., 2004). Imbalances in hydrology have substantially influenced many associated physical, ecological, chemical, and biological conditions. Channel enlargement, instability, channel erosion, and sediment transport were considered major physical effects of urbanization (Hammer, 1972; Bledsoe and Watson, 2001; Booth and Henshaw, 2001). Degraded stream habitat conditions or its complete removal when natural channels are replaced with pipes, ditches, and concrete channels, reduction in forested riparian corridors, increased fish blockages, reduced pool depth, roughness, and sinuosity, and decreased habitat diversity are common results from urbanization (Dunn and Leopold, 1978; Booth, 1991; Booth and Jackson, 1997; May et al., 1997; Wang et al., 2001). Increased runoff volumes and rates associated with urbanization increase pollutant export rates of sediment, nutrients, metals, organic and hydrocarbons, pesticides and herbicides that degrade water quality of surface waters (US EPA, 1983, 1998; Smullen and Cave, 1998; USGS, 1998, 1999). Urban runoff also delivers excess amounts of indicator bacteria and organic materials to the surface waters (US EPA, 1998; Pitt, 1998; Schuler, 1999) that limit contact recreational uses and lower dissolved oxygen levels due to increased biological oxygen demand. In addition, elevated stream temperatures were noted in many urbanized watersheds (Galli, 1990; Paul et al., 2001). All these effects and stressors eventually impacted the aquatic life ecosystem of water bodies by decreasing desirable aquatic insects and fish populations, decreasing biological diversity, decreasing sensitive organisms, and increasing pollutant tolerant organisms (Klein, 1979; Jones and Clark, 1987; Yorder, 1991; Weaver and Garman, 1994; Booth and Jackson, 1997; Horner et al., 1997; Wang et al., 2000, 2001). Figure 2-1 demonstrates a conceptual diagram summarizing the general linkage between land use changes and urbanization and the ultimate impacts on the natural aquatic life in waterbodies based on the literatures reviewed in this chapter.

As human population and resource usage continue to expand, it can only be expected that the urbanization process will continue to accelerate (Cooper et al., 2007). Subsequently, the pressure for effective water resources management are multiplied by factors including unpredictable economic growth in a globalizing economy, the introduction of new technologies whose potential side effects are unknown, increasing recognition of the need to preserve water resources and protect aquatic ecosystems, and the uncertainty related to climate variability and subsequent hydrologic predictions (NRC, 2001). It is important to note that the impacts of urbanization cover a wide range of disciplines although the impacts are inter-related or somewhat sequential as described in the previous paragraphs (Figure 2-2). A comprehensive consideration of all issues at the same time is vital not only to understand and identify the causes and sources of the issues, but also to implement the appropriate action by relevant parties so that the available resources are well utilized towards sustainable watershed management. Since these local environmental issues are cumulative and have global consequences as mentioned earlier, addressing these issues require 3C approach of stakeholders who live in the watershed with adequate governmental and scientific support, especially from different disciplines, through an interdisciplinary approach. By recognizing the success and failure of watershed management programs in addressing non-point source pollution in the United States since the implementation of Clean Water Act (CWA) in 1972, US EPA supports the implementation of holistic watershed planning because this approach usually provides the most technically sound and economically efficient means of addressing water quality problems and is strengthened through the involvement of stakeholders that might have broader concerns than solely attainment of water quality standards such as flooding, water supply, recreation, and aesthetics (US EPA, 2008). Such holistic planning, addressing these multi-disciplinary issues, should have at least the following characteristics for sustainable watershed management.

- Government Support
- Local Knowledge and Local Actions.
- Engaging all Stakeholders in Decision Making.
- Decision Making at Watershed Level
- Interdisciplinary Approach
- Integrating Science, Policies and Regulations into Decision Making
- Funding

The following sections provide the insight into the status of today's watershed planning in addressing the issues associated with urbanization and then it leads towards defining the present research including the need for the research, research objectives, and research approach/methodologies.

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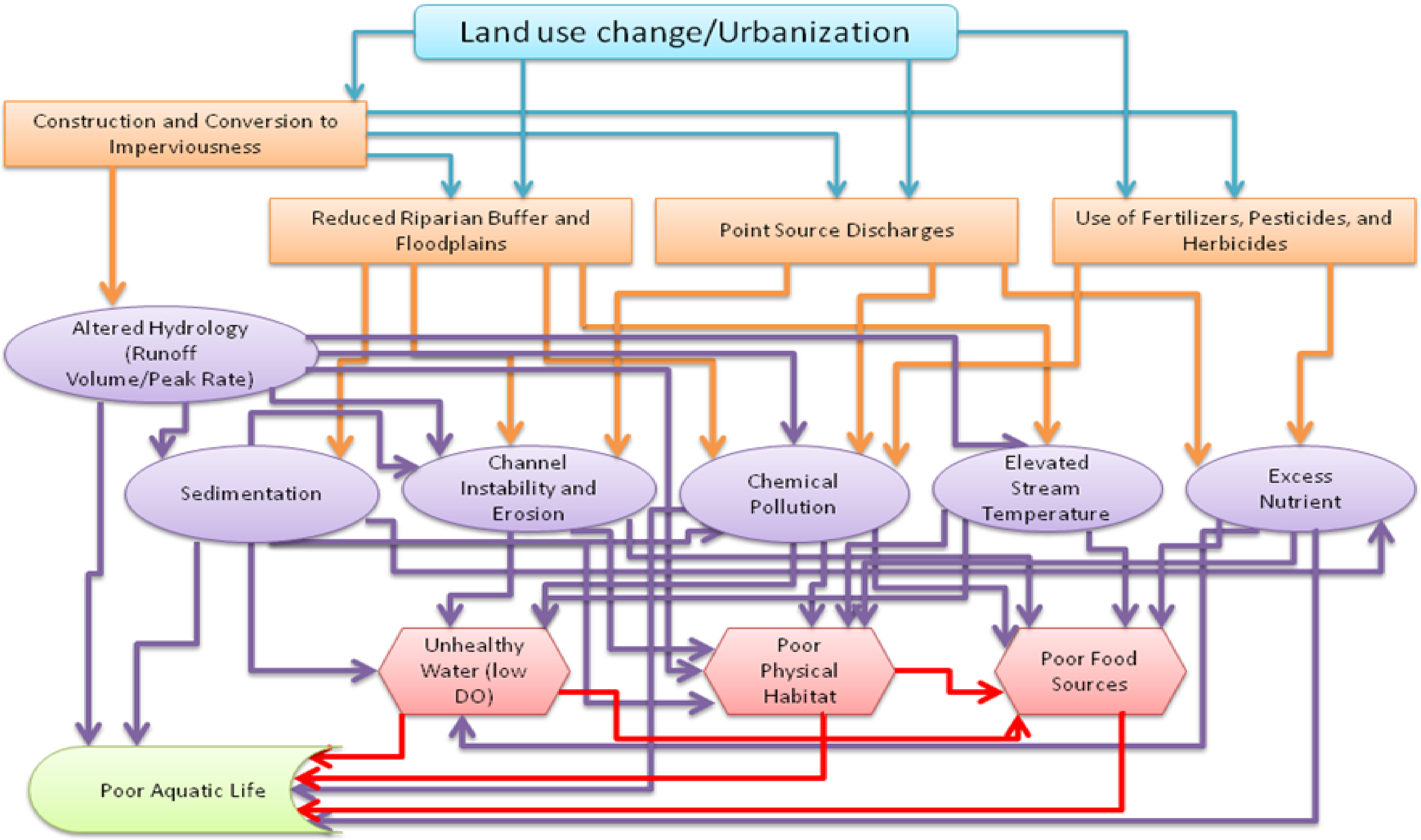

Figure 2-1. Conceptual Diagram linking the typical actions (orange) of land use changes and urbanization with its Impacts (purple) and the stressors (red) and effects to the aquatic life in a natural river system.

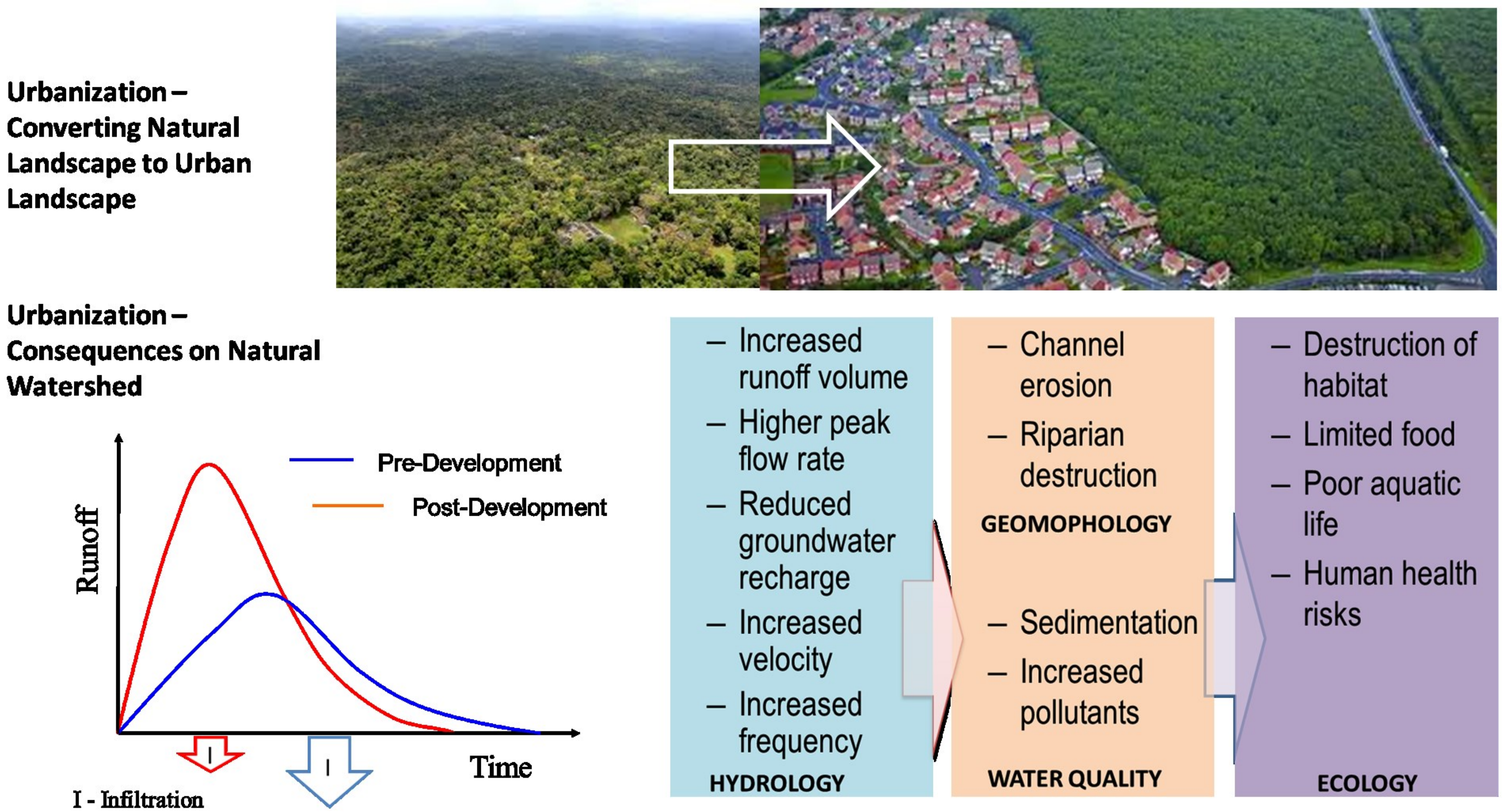

Figure 2-2. Multi-disciplinary nature and linkage of the impacts of urbanization.

2.2 TOP-DOWN APPROACH FOR WATERSHED PROTECTION

Traditionally, the management of water resources and the mitigation of urbanization impacts followed a top-down approach. This is logical to a certain level as environmental problems often cross local, regional, and sometimes national boundaries, and thus warranting governmental interventions (Carr, 2002). It is also acknowledged that national governments are somewhat better at implementing certain civic responsibilities and policies than state/provincial, or local governments (Carr, 2002). Most water management policies tend to emphasize uniform sets of structures, roles, and programs that are formulated at high levels to meet national goals and extend downward to provincial/state and local levels in a top-down manner (Thomas, 2008). In the United States, the Clean Water Act (CWA) is a legendary top-down water management example of the 20th century, through which billions of dollars were allocated for sewage treatment plant construction and industrial and urban runoff pollution abatement (Lant, 1999). Overall, the top-down approach presumes that natural resource management should be performed mainly by outside "experts" who are objective and rational, and fairness is achieved by treating different areas the same way (Smith, 2008; Thomas, 2008). Andreen (2004) attributed the successes achieved in the United States for the 30 year period since it was launched in 1972, to the same nationally implemented expert and technology based effluent limitations through National Pollutant Discharge Elimination System (NPDES) permit system under CWA. The following positive changes are a few highlights of CWA as reported by Andreen (2004).

1. The discharge of organic waste were reduced from publicly-owned wastewater treatment facilities by 46% while similar discharges from industry fell by 98%.
2. Dissolved Oxygen levels have increased downstream from point source discharges all over the country.
3. The rate at which the wetlands are lost in 1970s was reduced by 90%.
4. The amount of oil spilled was brought to one tenth of the level reported in 1970s.

Despite all these successes, CWA failed to address the non-point source pollution, i.e., 82% of the rivers and streams and 77% of estuaries failed to meet water quality standards due to the non-point source pollution from agricultural sources and from hydro modification of land use changes and urbanization (Andreen, 2004). In 1987, the federal statute was amended to promote community-based efforts to reduce nonpoint source pollution, often by developing and implementing watershed-based management plans (USEPA 1996, 2002, 2008).

Local inputs are often ignored or overlooked in the top-down approach. Early environmental policy and scholarly literature tend to portray local people as "obstacles" to efficient and rational organization of resources use (Agrawal and Gibson, 2001). Top-down experts tend to regard local representatives as not well suited for participating the intellectual decision-making process, mainly because local people typically do not have the relevant background in environmental management or earth science (including hydrology, forestry, ecology, geology, and biochemistry) (Carr, 2002). As a result, the top-down approach typically relies primarily on "expert" scientific knowledge and analysis concerning environmental issues and management options while excluding local people from participating in management discussions and decision-making that concern their own environment (Carr, 2002).

2.2.1 Examples of the Top-Down Approach

The implementation of Green Revolution concepts to the Punjab region in India is a good example of top-down approach in management of natural resources in developing countries. The Punjab region experienced a transformation of agricultural practices following the Green Revolution of the 1960s. With the overall goal of increasing crop yield, government subsidies were provided to Punjab farmers, including free electricity. As a result, the number of irrigation wells increased from 150,000 to nearly 19 million. The new network of decentralized groundwater users and application of fertilizers resulted in significant increase of crop yield, with the Punjab now producing nearly 20 percent of the country's wheat and 12 percent of rice on only 1.5 percent of the land (Cooley et al., 2013). The unintended consequences from the top-down management, however, include falling water tables and degradation of groundwater quality (Kumar et al., 2007). Today, the Punjab region is one of the most groundwater stressed areas in India (Rodell, 2009). The government now spends millions of dollars to rehabilitate surface water canals and reservoirs. Serious considerations of shifting from the energy-irrigation paradigm are needed if the government wants to curb groundwater overdraft and pollution (Cooley et al., 2013).

In addition to CWA driven top-down planning in USA, other developed countries launched several programs. A top-down planning approach was implemented in the Lower Saxony, Germany, to address water pollution issues related to nutrient runoff from the agricultural sources (Koontz and Newig, 2014). The Lower Saxony case faced considerable implementation challenges. While top-down directives from the state environmental agency (or as above that the national government and the European Union) were able to set in motion collaborative planning, the resulting plans did not drive implementation of the management recommendations contained therein. This was because the state agency did not seriously scrutinize the plans, nor did it use the plans to unlock funding. In the process of taking in many smaller scale plans, agency officials removed location-specific details and created a plan that was too general to guide specific actions on the ground. Moreover, funding from the state agency was based on the agency's priorities rather than on plan recommendations. Nevertheless, some implementation did occur, through local networks and actions separate from the state environmental agency.

Another example from Europe illustrates the top-down approach and the presence of a central authority at the river basin scale in Catalonia, Spain that spurred the development of a consolidated regional plan intended to encompass all phases of flood risk management., However, the degree of engagement and opportunities for knowledge-sharing among local participants were limited (Llobet et al., 2016). A summary of overall characteristics of top-down planning in addressing the multi-disciplinary issues of urbanization is provided in Table 2-1. A detailed evaluation on selected cases is reported in Chapter 3. The next section presents general criticisms of top-down approach.

2.2.2 Criticisms of the Top-Down Approach

Past experiences of the top-down approach in managing water resources at the governmental level proved to be insufficient in handling complex, site-specific water resources problems of the 21st century. In the Midwest as well as parts of the Northeast, South, and California of United States; many streams carry few of the ecological or aesthetic values they once did due largely to urbanization, intensive agriculture, and in some instances channelization (Lant, 1999). In the Midwest, the northern Great Plains, and the Central Valley of California, large areas of wetlands were drained, and thus losing valuable biological productivity, flood control, and the nutrient cycling functions (Lant, 1999). These water resource issues exemplify interdisciplinary characteristics that are common in many water resources management problems encountered across the country, which are not manageable through narrowly focused federally-funded engineering and federally-administered technological regulations (Lant, 1999). Governmental involvement in local environmental stewardship can be weakened by the rigidity, size, narrow focus, and culture of older style of "command and control" bureaucracies, which are further explained as follows.

Over centralization was one of the critique of the top-down approach. Although the centralized authority resulted in positive outcome in controlling industrial pollution (Moreau, 1994), building waste water treatment plants, and/or flood risk management, the degree of engagement and opportunities for knowledge-sharing among participants were limited (Llobet et al., 2016). The centralized policy and program had no clear delivery mechanism (Lovell et al., 2002) at the ground level specifically when the implementation and remediation actions are targeted at that level. Over centralized approaches tend to treat the environment entirely as scientific or technical ignoring societal implications related to successful implementation. However, the need for environmental management policies or programs are driven by societal needs. In addition, external technicians and bureaucrats would not or could not "embrace all aspects of activities that shape or influence the environment", especially at levels where effective actions may occur, namely the "bottom" or grassroots of society (Caldwell, 1972). Another critique of the top-down approach is its positivism, which originates from the naïve trust on technological fix (Carr, 2002). It is important to point out that scientific and technological solutions based solely on rational science are not solutions. As we can hope to alleviate certain effects from environmental degradation, such complex and widespread issues cannot be entirely "fixed" through limited perspective approaches (Carr, 2002). In addition, the blind reliance on research tends to alienate the "experts" from local residents and further fails to recognize local residents as potential sources of innovative ideas for complex problems (Carr, 2002). The reliance of technical or scientific fix by the outside experts leads to the next critique of missing local input from residents and community organizations who care about their own environment. The last, but not the least, criticism is that the agencies and experts tend to limit their focus within the respective discipline and, as a result, the inter-related multidisciplinary sets of causes and impacts often failed to get the interdisciplinary attention that is warranted. A summary of general critics of top-down planning is presented in Table 2-1.

Table 2-1. Summary on Top-Down Approach in Watershed Planning.

Features for Sustainable Watershed Management	Top-Down Planning in General (Lant 1999, Agrawal and Gibson 2001, Carr 2002, Koontz and Newig 2014, Llobet 2016, Cooley 2013,)
Government Policies and Programs	Yes, Government policies and programs drive the planning process
Government Support	Yes
Scientific/Expert Input	Yes
Funding – Government	Yes
Funding – Private	No
Local Action	Limited to plan implementing stage
Local Decision-Making	No
Local Collaboration	Limited to information collection
Local Knowledge	Limited to consultation
Land use/Urbanization Management	Limited, water pollution from agriculture, irrigation, flood control issues dominated most of the reported literature
Integrated Actions Among Government Agencies	No
Institutional Arrangement to Link Government with Local Watershed Groups	No
Facilitation of Watershed Planning and Decision Making	Limited to plan implementation stage
Interdisciplinary Approach	No
Limitations as Reported	• The issues with interdisciplinary characteristics, along with many other water resources management problems across the United States, are not manageable through federally-funded engineering and federally-administered technological regulations (Lant, 1999). • Top-down experts tend to regard local players as incapable of participating the intellectual decision-making process, mainly due to the fact that local people do not have the relevant background in environmental management or earth science (Carr, 2002). • The top-down approach presumes that natural resource management should be performed mainly by outside "experts" who are objective and rational, and fairness is achieved by treating different areas the same way (Smith, 2008). • Local inputs are often ignored or overlooked in the top-down approach. Early environmental policy and scholarly literature tend to portrait local people as "obstacles" to efficient and rational organization of resources use (Agrawal and Gibson, 2001). • The presence of a central authority at the river basin scale in Catalonia, Spain have led to a consolidated regional plan in encompassing all phases of flood risk management, but the degree of engagement and opportunities for knowledge-sharing among participants were limited (Llobet et al., 2016). • The centralized policy and program had no clear delivery mechanism (Lovell et al., 2002) at the ground level specifically when the implementation and remediation actions are targeted at that level.

2.3 BOTTOM-UP APPROACH FOR WATERSHED PROTECTION

It was not until the 1980s and early 1990s that the bottom-up approach became a priority issue and point of discussion for environmental governance (Smith, 2008). In the United States, the new governmental approach to watershed decision making emerged mostly as a result of dissatisfaction with the traditional top-down approach's ineffectiveness to deal with a variety of problems, including nonpoint source pollution, protection of coastal estuaries, water quality planning under the Total Maximum Daily Load (TMDL) provisions of the Clean Water Act, protection of aquatic species under the Endangered Species Act, and the development of management plans under the National Forest Management Act. These problems require detailed local knowledge and the coordination of multiple agencies, which has been proved difficult to accomplish under the traditional top-down strategy (Carr, 2002). The grass-root watershed management has become a social movement, not only in the US, but also in Brazil, Australia, and other countries (Lant, 1999). In comparison with the traditional top-down approach, the more recent collaborative approach involves face to face information exchange and problem solving among all relevant stakeholders, shifting from the old paradigm of decisions being made by far-off, faceless bureaucrats with little knowledge of or concern for how those decisions affect local conditions (Carr, 2002).

The bottom-up approach was born in response to the perceived limitations of the top-down approach (Smith, 2008). The overall goal of the bottom-up approach is to engage local knowledge into decision making and eventually to achieve a sustainable development paradigm. In practice, the bottom-up approach engages local people, groups, and communities to organize themselves to work together on locally based environmental problems or issues (Ortolano, 1997; Agrawal and Gibson, 2001; Carr, 2002). The bottom-up approach also believes that local knowledge should be valued, appreciated, and sought after, and local people themselves should be considered as appropriate experts on their local environments (Chambers, 1997). In general, local knowledge is no longer disregarded as irrational, amateurish, unsophisticated, and irrelevant (Vanclay and Lawrence, 1995). This is also applicable for local skills, experiences, and perspectives (Tsing et al., 2005). This reevaluation of local capacities, capabilities, and knowledge can be extremely empowering for local communities participating in local environmental management projects and programs (Smith, 2008).

2.3.1 Examples of the Bottom-Up Approach

The Alliance for Aquatic Resource Monitoring (ALLARM), a community science project of the Environmental Studies Department at Dickinson College, Carlisle, Pennsylvania, USA has been in place since 1986 (Wilderman et al., 2004). Over the course of the project, the operational mode switched from a top-down "community workers" model to a bottom-up "science by the people" model. In the top-down model, the role of volunteers is limited to sample collection for a scientific institution or agency, whereas in the bottom-up model volunteers define the problem, design the studies, collect and analyze the samples, and interpret the data – all in partnership with professional scientists (Wilderman et al., 2004). Comparisons of the two approaches indicated that while the top-down approach provides efficiency in data gathering, the bottom-up approach is more suitable for shifting the power and control of decision-making into the hands of community members and for building community capacity to continue gathering knowledge for action in a sustainable manner. The study also found that as the amount of community involvement increases, the need for programmatic and technical support increases dramatically, and there are also significant challenges to obtaining funding for scientists who wish to engage in this type of participatory research (Wilderman et al., 2004).

Rhoads et al. (1999) carried out a research in the Midwest of United States to evaluate the impacts of local watershed planning and decision-making in the management of water resources. Major findings from the study include that watershed management, although dependent on science and engineering, is a process that is fundamentally social in nature. Whenever environmental scientists and technical experts fail to overtly recognize the social nature of watershed management, a truly participatory approach to environmental decision making is hindered. Based on the recognition, a bottom-up conceptual model for a community based watershed management model was proposed, and the model is shown below in Figure 2-3.

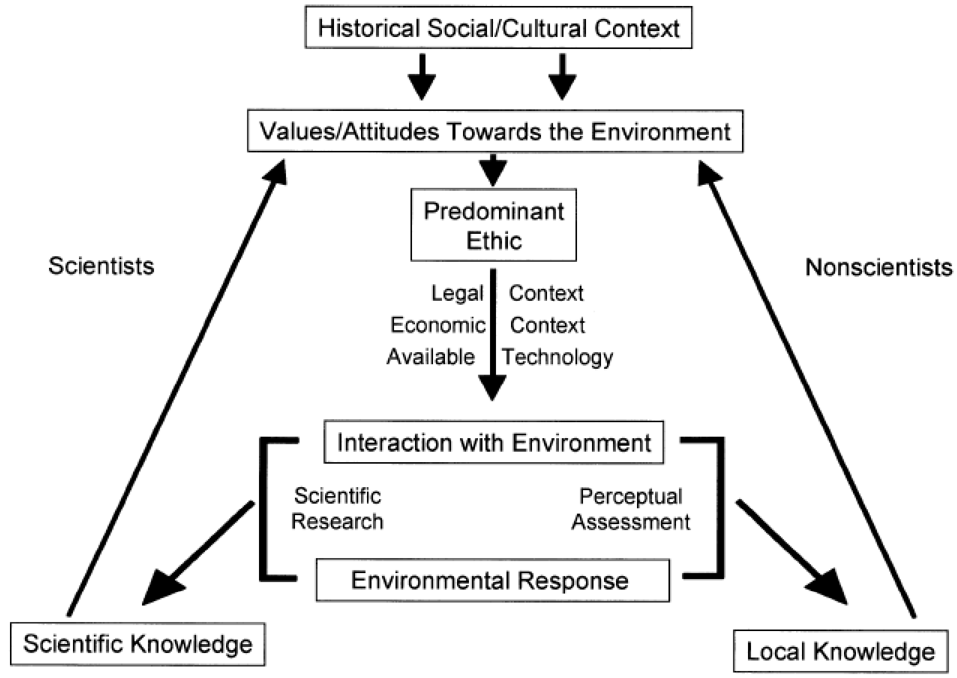

Figure 2-3. Conceptual bottom-up model for watershed management (from Rhoads et al. 1999).

As shown in the figure, the conceptual model includes diverse aspects of the nonscientific and scientific worlds: values, attitudes, ethics, historical inheritance, local knowledge, and scientific information. The model integrates contextual and locally rich factors into a general conception of social interaction between scientists and nonscientists within a community of local stakeholders. It represents community-based watershed management as a continuous cycle of interactions consisting of diverse participants and institutions with different and sometimes competing agendas and stocks of knowledge. The core of the model is the collective set of values towards the environment within a community made up with scientists and nonscientists. This conceptual model was considered as the alternative to a centralized scientific fix approach to watershed issues by incorporating local knowledge. It integrates the local knowledge with the expertise from the government and academic institutions that has been missing in traditional top-down approach. However, there is no evidence such a conceptual model was put it in practice for successful watershed management.

In the State of Ohio in the United States, the Department of Natural Resources (ODNR) Division of Soil and Water Resources and the Ohio Environmental Protection Agency (OEPA) encourage watershed partnerships to develop watershed action plans. While state officials are available for consultation, they do not direct the process. They provide guidance for how to create a plan and whom to include in its development, recommending the inclusion of watershed residents, land owners, businesses, community organizations, educational institutions, and state and local governments. Therefore, it can be categorized and reported as bottom-up planning with the support of the Government. Koontz and Newig (2014) reported three partnerships under Ohio's program, to address water pollution issues caused by nutrient runoff from the agricultural sources. A key finding was that these cases exhibited higher member perceptions that their collaborative efforts led to improved implementation and environmental conditions, compared with the Lower Saxony cases, reported as top-down. This difference is attributed less to top-down vs. bottom-up approaches per se, than to available resources, dedicated leaders, willing land owners, and active communication networks. In Ohio, collaborative planning emanated from local participants and organizations, and the resulting plan was passed up to the state agency (Ohio DNR), where it was carefully scrutinized. Upon endorsement, the watershed became eligible for various grants to carry out recommended actions. In addition, the state agency provided funds for some groups to hire full-time watershed coordinators. Although it was reported as bottom-up, the Ohio example has substantial government support which is not typical to other bottom-up cases reported. A summary of overall characteristics of bottom-up planning in addressing the multi-disciplinary issues of urbanization is provided in Table 2-2. A detailed evaluation on selected cases is reported in Chapter 3. The next section presents the general criticisms of bottom-up approach.

2.3.2 Criticisms of the Bottom-Up Approach

As promising as the bottom-up approach for being an alternative to the top-down approach, the bottom-up approach itself is also critiqued in several aspects for watershed management. Such critiques vary from tokenism (symbolic participation), community myth, local level capacity constraint, lack of facilitator knowledge, to inequity, all of which are further discussed below.

Although governmental and non-governmental environmental management projects are now increasingly emphasizing the validity and importance of local participation, there largely remains a gap between the official rhetoric and the reality on the ground (Nelson and Wright, 1995; Heyd and Neef, 2004; Marshall, 2005). In other words, communities become mere information providers and are involved at best for consultation, not in the more important and effectual processes of decision-making (Heyd and Neef, 2004; Wilderman et al., 2004). Local participation then becomes passive and tokenistic rather than active and meaningful (Smith, 2008).

Tokenism can originate from the unwillingness of government agencies, officers, and representatives to devolve power to lower levels such as the community, or alternatively because of the overriding top-down structure within communities and municipal governments, coupled with the lack of capacity and competency to sustainably manage their local resources (Heyd and Neef, 2004). A tokenistic participatory process can also occur due to the lack of a functional facilitating platform (McIvor, 2000; Smith, 2008).

In most discussions of the bottom-up approach, local communities are romantically simplified as idyllic, cohesive, organic, harmonious, and homogeneous entities, sharing common interests, aims, and goals (Agrawal, 1999; Dreyer, 2000). However, these happy images of undifferentiated wholes are problematic and need to be challenged if more realistic descriptions of the participatory process are to be provided and the unquestioned acceptance of traditional overly simplistic naive notions of "community" are to be abandoned (Smith, 2008). It is clear that rather than being a homogeneous group of people and interests, communities are more usually a collection of many different people, stratified by age, religion, gender, ethnicity, values, economic position, social status, political power, and life experiences (USEPA, 1995;, Smith, 2008).

A successful watershed management framework must identify, understand, and accommodate community heterogeneity. When adequate time is not expended to critically analyzing the inherent complexity of community dynamics and its various heterogeneous elements, outcomes of resource management projects, policies, and programs can be adversely effected (Agrawal and Gibson, 2001; Lane and McDonald, 2005).

Another common critique to the bottom-up approach of watershed management is the financial capacity constraints. While communities hold valuable knowledge about local environments and are enthusiastic, motivated, and committed to water management projects, the additional essential element of material resources and social capital is also necessary for ensuring successful and sustainable community water management projects (Cleaver, 2001; Lane and McDonald, 2005). The requirements of resources can take several forms: First, the necessary human, social, and economic capital to undertake necessary tasks in an effective fashion. Second, the ability to perform effectively within appropriate time frame, giving the urgency of existing environmental problems. Third, the jurisdictional authority to intervene in resource management across multiple tenures. Fourth, the legitimacy to act (Lane and McDonald, 2005). Unfortunately, such resources are often lacking in local communities, particularly for rural, socially isolated, economically, and politically marginalized in developing countries (Cleaver, 2001; Smith, 2008).

A fourth problematic element of the bottom-up approach is that people charged with the responsibility of facilitation lack the knowledge about community participation (Dreyer, 2000). Corresponding with the increasing popularity of the participatory paradigm, civil servants, corporate representatives, volunteer workers and project planners are also expected to deeply involve local communities to participate in environmental and water management. The concept and process of participation of local people in such process, however, is not properly understood (Dreyer, 2000). One disturbing fact is that people without the necessary skills, capacity, and confidence are increasingly required to facilitate and initiate community participation activities (Dreyer, 2000; Smith, 2008).

The knowledge of staff members and volunteers on effective engagement with local communities can be improved through a holistic approach towards training and preparation (Chambers, 1997). The approach includes background research, review of training guides, interactive forums and seminars for open discussion with people with ample local knowledge, and visits to areas and communities that have been involved in participatory-based initiatives (Chambers, 1997; Smith, 2008).

The fifth and final critique to the bottom-up water management approach is inequity. While decision-making at the local or community level increases homogeneity and increases the importance of the local distribution of power, it also enhances the potential for inequality (McConnell, 1966). The inequitable distribution of resources and access in bottom-up programs has been identified as one of the major problems in a number of cases, indicating that some interests are under-represented while others enjoy privileged access to policy makers (Sarin, 1995).

The understanding and appropriate response to the possibility of inequality requires a concept of community that is inclusive of multiplicity and difference, and an understanding that the community is subject to the exercise of power (Lane and McDonald, 2005). Secondly, it needs to be realized that participatory and political abilities are rarely distributed uniformly, and certain participants will be less articulate and influential. The last principle refers to the recognition that where power differentials exist across multiple actors, the likelihood of unequal distribution of resources is high (Lane and McDonald, 2005).

Several remedies are available for ensuring equity in the bottom-up approach. In general, it is suggested that the bottom-up approach needs to acknowledge the diversity of local actors, the multiple scales at which they operate and the importance of mediating conflict and power differentials between and among local actors. Four specific remedies are suggested for deliberately account for unjust or inequitable outcomes: 1. Use of a flexible definition of "community" based on its observable characteristics and as appropriate to the natural resource problem being addressed, 2. Maintenance of an explicit conflict resolution capacity for mediating between diverse and competing actors, 3. "Active" facilitation of the expression of views from all interests, and 4. Maintenance of the role of formal institutions in resource management to perform mediation function and to account for the values and interests of actors at wider scales (Lane and McDonald, 2005).

Table 2-2. Summary on Bottom-Up approach in Watershed Planning.

Features for Sustainable Watershed Management	Bottom-Up Planning in General (Carr 2002, Heyd and Neef, 2004, Smith 2008, Koontz and Newig 2014)
Government Policies and Programs	No (Unless it is supported or initiated by Governments)
Government Support	No (Unless it is initiated by Governments)
Scientific/Expert Input	No (Unless it is supported by Governments)
Funding – Government	No (Unless it is initiated by Governments)
Funding – Private	Yes
Local Action	Yes
Local Decision-Making	Yes (Limited, if it is supported or initiated by Governments)
Local Collaboration	Yes
Local Knowledge	Yes
Land use/Urbanization Management	No
Integrated Actions Among Government Agencies	No
Institutional Arrangement to Link Government with Local Watershed Groups	No
Facilitation of Watershed Planning and Decision Making	No (Unless it is supported by Governments)
Heterogeneity in Community Participants	Not all cases reported
Interdisciplinary Approach	No
Limitations as Reported	• Communities become mere information providers and are involved at best for consultation, not in the more important and effectual processes of decision-making (Heyd and Neef, 2004; Wilderman et al., 2004). Local participation then becomes passive and tokenistic rather than active and meaningful (Smith, 2008). This characteristics were observed at bottom-up approach was somehow forced by the government, development agencies or outside NGOs. • Tokenism can originate from the unwillingness of government agencies, officers, and representatives to devolve power to lower levels such as the community, or alternatively because of the overriding top-down structure about communities, coupled with the lack of capacity and competency to sustainably manage their local resources (Heyd and Neef, 2004). A tokenistic participatory process can also occur due to the lack of functional facilitating platform (McIvor, 2000; Smith, 2008). • It was simplified inappropriately as idyllic, cohesive, organic, harmonious, and homogeneous entities, sharing common interests, aims, and goals (Smith, 2008). A successful watershed management framework has to identify, understand, and accommodate community heterogeneity. When not enough time is being paid to critically analyzing the inherent complexity of community, their heterogeneous elements can affect outcomes of resource management projects, policies, and programs (Agrawal and Gibson, 2001; Lane and McDonald, 2005). • The necessary human, social, and economic capital to undertake necessary tasks in an effective fashion, the ability to perform effectively within appropriate time frame, giving the urgency of existing environmental problems, the jurisdictional authority to intervene in resource management across multiple tenures, and the

	legitimacy to act are considered as necessary material resources and social capital (Lane and McDonald, 2005). Unfortunately, such resources are often lack in local communities, particularly for rural, isolated and socially, economically, and politically marginalized in developing countries (Cleaver, 2001; Smith, 2008). • One disturbing fact is that people without the necessary skills, capacity, and confidence are increasingly required to facilitate and initiate community participation activities (Dreyer, 2000; Smith, 2008). • The inequitable distribution of resources and access in bottom-up programs has been identified as one of the major problems in a number of cases, indicating that some interests are under-represented while others enjoy privileged access to policy makers (Sarin, 1995). The understanding and appropriate response to the possibility of inequality requires a concept of community that is inclusive of multiplicity and difference, and an understanding that the community is subject to the exercise of power (Lane and McDonald, 2005).

2.4 THE HYBRID APPROACH

While central governments tend to focus on higher levels of organization and the needs of broader populations, local communities are more concerned with issues at local levels (Thomas, 2008). It can be challenging to definitively group cases into either top-down and bottom-up approaches. Some cases, claimed as top-down, included the features of bottom-up and vise-versa. How an approach is implemented seems to have more influence in success or failure of such approach rather than how the approach is defined. In recognition of the limitations of both the top-down and the bottom-up approaches, there are suggestions that the two approaches be linked to form a hybrid approach for watershed management (Lane and McDonald, 2005). In pursuing such a strategy, the common differentiation of “bottom-up” and “top-down” has to be abandoned in favor of a more nuanced appreciation of possible contributions of planning at both ends of the continuum (Lane and McDonald, 2005). A common framework in which both approaches can interact in constructive and mutually reinforcing ways seems to be a reasonable approach forward (Thomas, 2008). A comparison of six cases in two states (Lower Saxony, Germany as top-down cases and Ohio, United States as bottom-up cases) indicates important differences in perceptions of implementation and environmental improvements, although whether an effort was more top down or more bottom up was not a key determinant of results (Koontz and Newig, 2014). It further solidifies the hybrid concept by integrating the merits of both top-down and bottom-up approaches while eliminating the limitations.

The hybrid approach is also the logical conclusion from past experiences. Following the United Nations Conference for the Environment and Development (UNCED) in Rio de Janeiro in 1992, the concept of integrated management of land, water, and forests are well accepted and are implemented in many nations (Lovell et al., 2002). However, few of these national programs delivered the desired results, despite considerable efforts and interests, mainly because of the fact that the top-down approach was not coupled with community involvement in the process, and there was a lack of appropriate delivery mechanism at ground level to generate the interest and support of local institutions and communities (Lovell et al., 2002). As a matter of fact, the lack of appropriate delivery mechanism was identified as the main reason for failing in attempts of integrated watershed management in both Australia and South Africa (Blackmore, 1995).

In the exploration of the potential of sub-basin level water management processes in northern Thailand, Thomas (2008) tested the combination of top-down and bottom-up approaches in three pilot sub-basins of the Ping River Basin, with particular focus on organization and planning. A conceptual model was presented that includes both top-down activities that focus on larger scales and issues at higher levels of social organization and bottom-up activities based on local conditions, concerns, and capacities (Thomas, 2008). The watershed sub-basins serve as the venues where the two approaches interact. The study also raises the point that there is need for all parties to recognize that water management is a long-term process with support and capacity building needs that change over time. The hybrid approach aims for creating a learning process based on participatory monitoring of actual results and their effects on livelihoods and natural resource sustainability (Thomas, 2008). All these aspects were presented with little or no evidence-based assessment rather than with overviews and conceptual conclusions.

Lovell et al. (2002) compared both the top-down approach and the bottom-up approach for integrated watershed management (Figure 2-4) and proposed a framework for effectively linking community-based projects with larger, structured programs. The hybrid approach needs to occur through a structured program that provides overall planning, coordination, and long-term financial support for activities at regional or catchment level (Lovell et al., 2002). Essential features of the hybrid approach are the common interest group, the development process that facilitates participation in joint action, and the structured program, the combination of which are expected to overcome the lack of overlap between different physical areas and social groupings associated with the management process (Lovell et al., 2002).

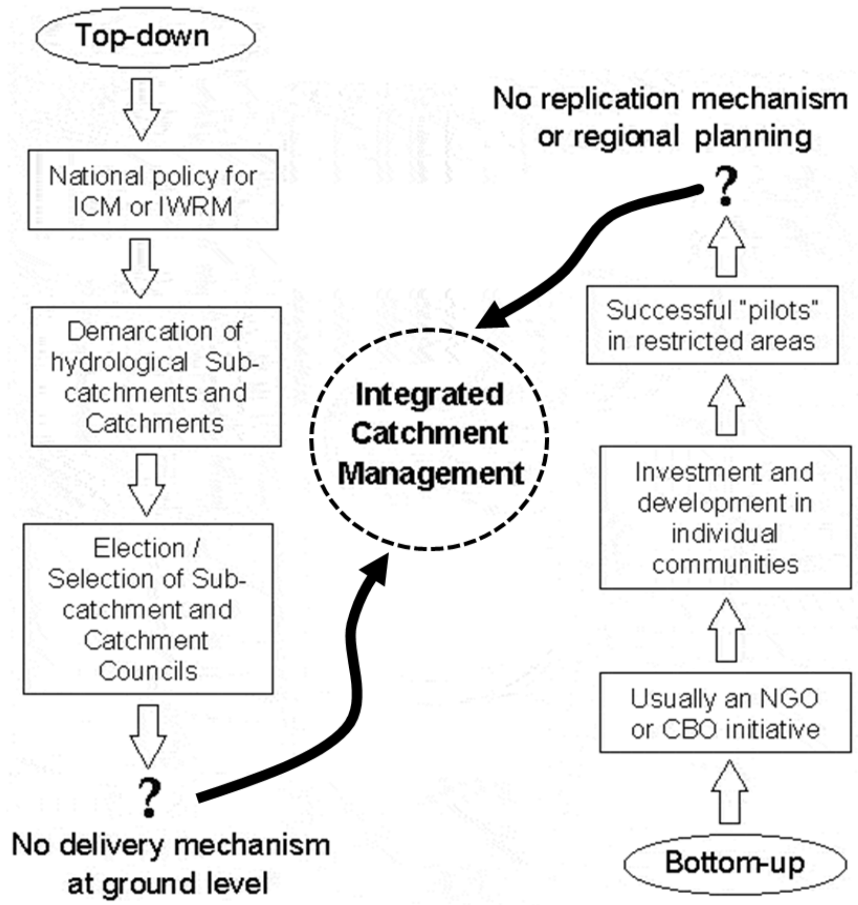

Figure 2-4. Analysis of the limitations in the top-down and bottom-up watershed management approaches and the concept of a hybrid approach (adapted from Lovell et al., 2002).

2.5 REMAINING GAPS

Although the hybrid approach represents the future of watershed management, there are still gaps to be filled before a functioning hybrid model can be established for effective, long-term watershed management. Such gaps include the implementation of interdisciplinary approach, development of self-sustaining institutional model, accommodation of social sciences, etc. Appropriately fulfilling these remaining gaps is crucial for building successful watershed management models in addressing today's unique challenges such as resulting from urbanization impacts.

2.5.1 Interdisciplinary Approach

Water resources problems are extremely complex and dynamic in space and time, and thus requiring solutions to cross traditional disciplinary and social boundaries. While anthropologists, geographers, political scientists, psychologists, and sociologists were not always involved in water resources research in the past, their contributions have to be recognized and effectively incorporated in the twenty-first century watershed management programs (NRC, 2001). In addition, government entities, community groups, business and industrial organizations, and the public have to be included in the participatory and interdisciplinary approach (Hooper, 2003). The interdisciplinary approaches have been extended by the Global Water Partnership (2000) as well as the 2003 Summit on Sustainable development in Johannesburg, South Africa and Third (2003) World Water Forums in Kyoto, Japan.

The development and maintenance of the interdisciplinary approach requires many elements. One element is the establishment of a strong knowledge base that derives from a comprehensive and interdisciplinary data networks, systems, and models. The knowledge base will help design and implement informed water management policies and strategies (Hooper, 2003). A second element is the integrated action across all water management issues, which means that no singular solutions are sought and impacts and improvements across the spectrum of water management are evaluated (Hooper, 2003). A third element is the promotion of strong community awareness and participatory process, which is to enhance stakeholder involvement in the management decision-making (Hooper, 2003).

2.5.2 Self-Sustaining Institutional Model

It is natural that watershed management programs change and evolve over time. For example, programs often focus on one initial problem before expanding their interests to other issues (Selin and Chavez, 1995). Or they may increase the scope of their activities or geographic concern (Huntington and Sommarstrom, 2000). Watershed management programs, depending on their level of associations with the government, could have varying levels of endurance and stability (Genskow and Born, 2006). All of these make it imperative and meaningful to develop self-sustaining institutional models for watershed management.

The development of self-sustaining institutional models requires many considerations, including the creation of a stable framework that overcomes fragmentation and overlap of responsibilities; the use of institutional arrangements such as cost-sharing programs, tradable discharge permits, local government planning powers, voluntary actions, regulatory practices, and more; organizational structures such as skills-based membership, democratic and accountable systems, and access to high levels of government; maintenance of effective coordination of civil and professional science; and development of shared visions across all institutional levels, based on careful problem analyses (Lovell et al., 2002; Hooper, 2003).

2.6 STATE-OF-THE-RESEARCH

The urbanization process exerts multidisciplinary impacts to the environment, and thus incurs a comprehensive management model to address the adverse hydrological, ecological, and water quality consequences. Starting with an interdisciplinary perspective, the goal is to establish a self-sustaining and effective institutional model that can be used in watersheds across geographical and political boundaries while accommodating the urbanization process to meet the socio-economic goals. Neither the top-down nor the bottom-up approach has been sufficient for solving today's watershed management problems. As a result, the hybrid approach is proposed as a promising concept and is regarded as the future for effective and sustainable water management.

Since the hybrid approach concept is still relatively new, there are remaining knowledge gaps to be filled before it can be widely adopted for watershed management in general. First and foremost, there exists very limited knowledge on how a functional institutional model can be established for effective watershed management, specifically on self-sustaining institutional structure that supports interdisciplinary decision making. Limited knowledge exists regarding the mechanisms of feasible decision-making processes and sustaining such mechanisms at watershed level, especially for practical case studies that can be referred to. Not only in the hybrid approach, but also in the bottom-up approach, the evident base assessments are very limited, that's why one of the studies by Organization for Economic Cooperation and Development (OECD) stressed this point and attempted to collect evidences in stakeholder engagement throughout its member countries (OECD, 2015). Even in this case, it was limited to water governance in large scale, such as water demand and water scarcity issues, flood disaster management, policy reforms, large scale dam projects, etc. Most importantly, to date no hybrid model has been proposed or developed to specifically address the challenges associated with urbanization.

2.6.1 Objectives

Towards contributing needed knowledge in the missing area, the research defined three objectives as follows.

1. To develop a new management framework that can overcome the limitations of both top-down and bottom-up approaches and to provide a self-sustaining institutional structure for interdisciplinary decision making at the watershed level.
2. To validate the new framework on a real world field application.
    - Analyze the linkage of issues and address them through interdisciplinary approach for water resource management and improving environmental water quality.

    - Investigate the decision-making process and the mechanisms to sustain it.
3. To further enhance the framework with lessons learned from implementation.

2.6.2 Research Approach/Methodology

The three research questions, on how to address the complicated urbanization challenges, have motivated this research and are presented as follows:

1. What is the role of the hybrid approach in bringing the interdisciplinary approach?
2. Did the successful cases succeed because of hybrid approach?
3. Would the successful cases have succeeded the same way without hybrid approach?

As a result, the research approach, presented in this section, focuses on meeting the objectives while attempt to answer these questions. An outline is also presented in Figure 2-5.

Objective 1: To Formulate New Management Framework

Formulate a new management framework by analyzing practical cases (from scholarly literature published in peer reviewed journals and books) on both top-down and bottom-up approaches through Strength, Weakness, Opportunity, and Treat (SWOT) analysis. Integrate the necessary features by accommodating the strengths while eliminating the weakness or major causes of weakness.

Also integrate the necessary conditions, identified from literature, for interdisciplinary approach and self-sustaining model into the framework as a theoretical self-sustaining institutional model for interdisciplinary decision making at watershed level.

Objective 2: To Validate New Management Framework

Validate formulated framework, specifically major elements and necessary condition, by comparing them in selected practical cases (from project reports published by government agencies and others), where watershed management plans were developed for addressing urbanization issues, through a baseline analysis. Select a successful case for a detailed investigation (Shawsheen River Watershed in USA).

Investigate in detail by examining technical reports, meeting summaries/minutes, baseline inquiries from stakeholders, notes from in-person meetings and other available data and information from Shawsheen during a self-management stage (between 1998 and 2003) as well as by analyzing the environmental improvement after a decade of plan development through available data and information, stakeholder meeting and inquires, and field visit.

- Analyze the linkage of three issues, flow, bacteria, and aquatic life impairments, and address them through interdisciplinary decision making in a systematic four step process; problem identification, problem recognition, problem investigation/implementation planning, and problem solving/implementation action.
- Examine the process of decision making and the mechanism to sustain such processes by evaluating the three issues in four steps, specifically a detailed review on conflicts, confusions and agreements and resolution mechanisms.

Objective 3: To enhance NMF into general institutional Model

Analyze the framework from a theoretical, practical, and policy prospective on capacity building at the watershed level and organizational and functional capacities.

Reevaluate the framework, major elements and necessary conditions, from the lessons learned, especially adding or amending the necessary conditions from the evidence of field implementation.

Present the enhanced management framework as a general institutional model, Grass-root Watershed Management (GWAM) Model with defined structure, processes, function and the mechanism to sustain them, so that meaningful planning, actions and management can be applied to address the watershed issues associated with urbanization at watershed level.

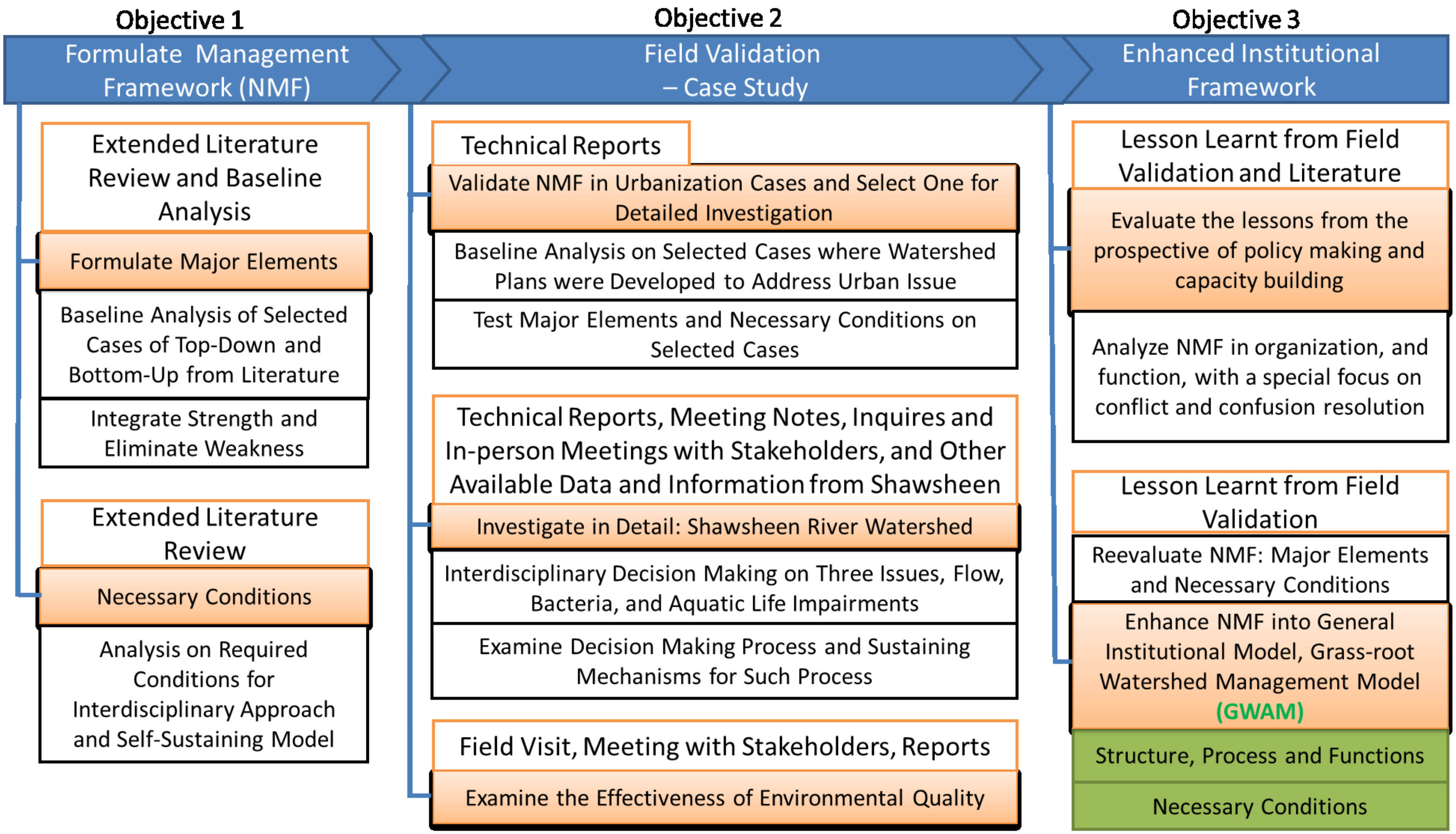

Figure 2-5. An outline of research approach/methodology to meet the three objectives of the research.

3.0 THEORITICAL NEW MANAGEMENT FRAMEWORK

The first objective of this research is to develop a new management framework (theoretical) that can overcome the limitations of both top-down and bottom-up approaches and to provide a self-sustaining institutional structure for interdisciplinary decision making at the watershed level. This Chapter provides the details on how the new management framework was developed. Four top-down and four bottom-up planning case studies from scholarly literature (peer reviewed journal and books) were analyzed to formulate the desired major elements of the framework for addressing urbanization at watershed level. This process involves integrating strengths, excluding weaknesses and including means to avoid identified weaknesses. Finally, additional elements/ conditions considered necessary for supporting an interdisciplinary approach and self-sustaining model were identified, in part from additional literature reviews, and integrated into the framework as well. An analysis of the sufficiency of the framework to meet the necessary conditions is also presented here. The conceptual framework, in concise version, was recently published in the Journal of Water Resources and Protection (Saravanapavan and Yamaji, 2018a).

3.1 FORMULATING NEW FRAMEWORK

Building on the existing body of knowledge of the bottom-up and the top-down approaches, the tenet of the new management framework is to overcome the limitations in both approaches while retaining and effectively integrating their advantages. Different from the conceptual hybrid watershed management models proposed by Thomas (2008) and Lovell et al. (2002), which mostly remain conceptual, the overall goal of this research is to propose a theoretical framework (theory) and test a hybrid and self-sustaining watershed management framework in a practical set up for mitigating urbanization impacts (practice), which will eventually lead to a practical institutional model (policy) that can be readily implemented in different watersheds.

This section reports on the review of eight international case examples of top-down and bottom-up planning (4 of each analyzed). Each of these cases was evaluated through conducting a Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis, primarily focuses on strengths and weakness. A new management framework was formulated by integrating strengths, excluding weaknesses and by filling element/condition gaps.

3.1.1 International Examples on Top-Down Approach

Four case studies were identified and each was analyzed for the strengths and weaknesses of the top-down approach with a focus of identifying key elements to include and avoid for the new management framework for sustainable watershed management at watershed level.

1. ***Lower Saxony Watershed Partnership, Lower Saxony, Germany (Primary Reference: Koontz and Newig 2014)***

The European Union (EU) Water Framework Directive1 of 2000 requires all EU member states to achieve "good status" of water quality by 2015. Member states must develop River Basin Management Plans and Programs of Measures that assess current water conditions and describe actions to be taken to achieve the targets. These plans were required to be completed by 2009 and submitted to the European Commission in Brussels by spring 2010.

Water quality is the major issue that has spurred collaborative watershed management efforts in Lower Saxony Watershed. Agriculture is a dominant land use, growing mainly corn, sugar beets, potatoes, and wheat. Nutrient runoff from agriculture runoff is a key source of water pollution in the watershed. In 2005 the Lower Saxony Ministry of Environment established watershed-based Gebietskooperationen ("area cooperations") to provide a forum for dialogue between administrators, water management stakeholders, and the public in developing plans to achieve water quality standards. The Ministry of Environment indicated the hope that these deliberative bodies would develop innovative proposals and bring new perspectives into planning. The bodies were given a timeline to develop monitoring programs by 2006, create management objectives and recommend waterbodies for listing as "heavily modified" (and therefore subject to less stringent regulations) by 2007, and contribute to the Program of Measures (actions to take) by 2008. After consolidating several small watersheds in Lower Saxony, 28 area cooperations were constituted. The Ministry of Environment established that area cooperation membership should include permanent members representing the most important water stakeholders in the watershed, such as counties, communities, consumer associations, agriculture/farming and forestry, water suppliers, industry, environmental organizations, and the state environmental agency NLWKN (Lower Saxony Land, Water, Coast, and Nature Protection agency). In 2005, the NLWKN facilitated area cooperation establishment of permanent members and a leadership team of two people, leader and manager. NLWKN personnel often served in these roles; across Lower Saxony, NLWKN personnel served as leader in over half of the area cooperations and manager in over 80 percent of the area cooperations. The Lower Saxony Minister of Environment provided 15,000 Euros per year to each area cooperation, starting in 2006, to support their work.

The three area cooperations that were evaluated by Koontz and Newig (2014) met approximately two to three times per year, starting in 2005. The leaders, working closely with NLWKN, developed meeting agendas and facilitated the meetings. Over several years, the area cooperations focused on water quality assessment, identifying heavily modified water bodies, and developing and prioritizing suggested measures to improve water quality. Each area cooperation developed lists of recommendations through collaborative interactions with a wide range of stakeholders.

A key challenge for implementation in Lower Saxony was the disconnection between levels in the federal system. As described below, top-down influence is exerted from state to local collaborative planning, but the resulting plans do not inform state-level planning or unlock resources from the state to implement the recommended actions (see Figure 1). Neither the plans nor the collaboratively created lists of recommended measures are significant drivers of action on the ground. While top-down directives from the state environmental agency (and above that the national government and the European Union) were able to set in motion collaborative planning, the resulting plans did not drive implementation of the recommendations contained therein. This was because the state agency did not seriously scrutinize the plans, nor did it use the plans to unlock funding. In the process of taking in many smaller scale plans, agency officials removed location-specific details and created a plan that was too general to guide specific actions on the ground. Moreover, funding from the state agency was based on the agency's priorities rather than on plan recommendations. Nevertheless, some implementation did occur, through local networks and actions separate from the state environmental agency.

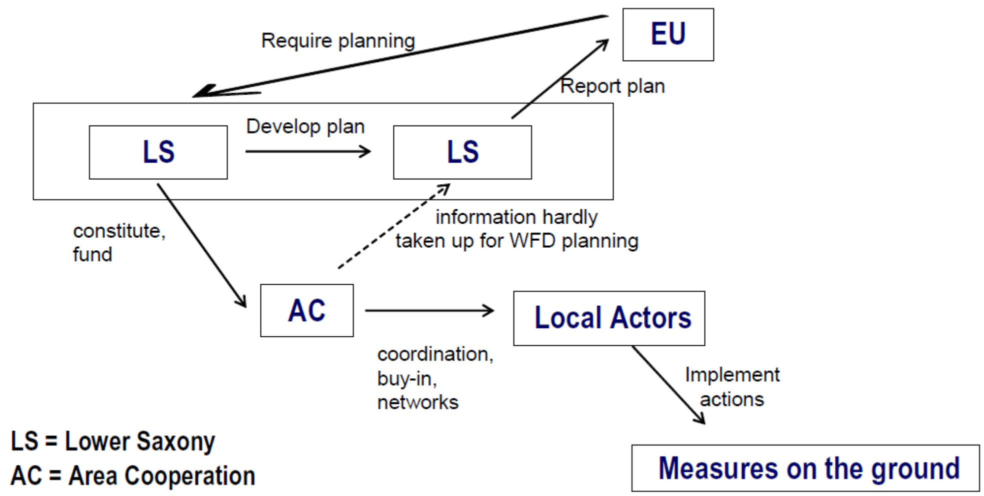

Figure 3-1. Top-down watershed planning at Lower Saxony, Germany (Adopted from Koontz and Newig, 2014)

2. Green Revolution Project in Punjab, India (Primary Reference: Cooley et al., 2013)

Implementation of Green Revolution concepts to industrialize agriculture in the Punjab region of India provides an example of a top-down, single-focus transfer of knowledge and technology that has led to several unintended consequences. Today, the state of Punjab is trying to manage these problems by revisiting and reforming state agricultural policy and regulations using a more bottom-up technology and knowledge transfer approach. It provides a typical example of narrowly focused top-down approach in management of natural resources in developing countries by outside experts and development agencies but without broader interdisciplinary representation and local knowledge.

The Punjab region experienced an intentional transformation in agricultural practices following the Green Revolution of the 1960s. Changes in cropping patterns, water use, and fertilizer use helped Punjab to become the country's "bread basket", the region produces 20% of the country's wheat and 12% of the rice on only 1.5% of the land. Part of this success can be attributed to government subsidies that provide free electricity to farmers in Punjab and heavily subsidized electricity in other parts of the country (Sarkar 2012). Between 1950 and 2000, the number of irrigation wells outfitted with diesel or electric pumps increased from 150,000 to nearly 19 million (Shah 2009). This new network of decentralized groundwater users and application of fertilizers, however, has resulted in falling water tables and worsening groundwater quality (Shah 2009, Kumar et al. 2007). Despite government attempts to regulate groundwater development, overexploitation of groundwater and excessive nutrient loading persist. The Punjab region is one of the most groundwater stressed areas in India (Rodell 2009). The government continues to invest millions in developing and rehabilitating surface water canals and reservoirs, although farmers increasingly rely on privately owned groundwater pumps (Shah 2009, Sarkar 2012).

Shiva (1991) described that the Green Revolution was a failure. It has led to reduced genetic diversity, increased vulnerability to pests, soil erosion, water shortages, reduced soil fertility, micronutrient deficiencies, soil contamination, reduced availability of nutritious food crops for the local population, the displacement of vast numbers of small farmers from their land, rural impoverishment and increased tensions and conflicts. The beneficiaries had been the agrochemical industry, large petrochemical companies, manufacturers of agricultural machinery, dam builders and large landowners. The "miracle" seeds of the Green Revolution had become mechanisms for breeding new pests and creating new diseases. In 1970, Norman Borlaug was awarded the Nobel Peace Prize for his work in developing high-yielding varieties (HYVs) of wheat. The "Green

Revolution", launched by Borlaug's "miracle seeds", was often credited with having transformed India from "a begging bowl to a bread basket", and the Punjab was frequently cited as the Green Revolution's most celebrated success story. Yet, far from bringing prosperity, the Green Revolution had left the Punjab riddled with discontent and violence. Instead of abundance, the Punjab was beset with diseased soils, pest-infested crops, waterlogged deserts and indebted and discontented farmers. Instead of peace, the Punjab had inherited conflict and violence. Shiva (1991) attributed the failure to the Indian government's narrow focus on food production with outside expertise from national and international experts and programs, especially through, US Agency for International Development (USAID), World Bank, Rockefeller Foundation and Ford Foundation, without looking into the local knowledge, local input and local and traditional ecology based agricultural system.

3. ***Neuse Watershed Planning, North Carolina, USA (Primary References: NC DENR 2012)***

The state of North Carolina in the United States began developing regulations for water quality relatively early compared to other states. In 1951, the state enacted a comprehensive pollution control program designed to protect water quality throughout the state. As with many of the early state programs, this effort targeted mostly point sources of pollution. North Carolina's development of a watershed protection approach to water quality began in 1986 with a voluntary program administered by the Environmental Management Commission. The state enacted the Water Supply Watershed Protection Act in 1989. The law required that local governments with land use planning jurisdiction within water supply watersheds adopt management plans and ordinances to protect the watersheds. The Environmental Management Commission (EMC) developed the Water Supply Watershed Protection Rules in 1992 to implement the Act's provisions specifying management requirements and watershed protection standards. The state attempts to coordinate interjurisdictional efforts within each watershed to ensure that multiple localities will meet the watershed standards. The Act strives to encourage watershed wide planning and management efforts, not simply focusing on a particular point on a waterway. Recognizing that other issues besides water supply quality need to be considered in watershed management, the state introduced the Basin-wide Water Quality Planning Program and completed the first set of plans for all North Carolina river basins in 1998. The Division of Water Quality develops a Basin-wide Water Quality Plan for each of the state's watersheds over a five-year period.

The Neuse River Basin-wide Water Quality Plan (NC DENR, 2002) was one of the first plans developed under this statewide program. The Neuse River originates in north central North

Carolina in Person and Orange counties and flows southeasterly until it reaches tidal waters near Streets Ferry upstream of New Bern. At New Bern, the river broadens dramatically and changes from a free-flowing river to a tidal estuary that eventually flows into the Pamlico Sound. The Neuse River basin is the third largest river basin in North Carolina and is one of only four major river basins whose boundaries are located entirely within the state. From 1982 to 1997 urban and built-up land cover increased by 919 square kilometers (km^2). Uncultivated cropland and pastureland also increased by 243 km^2. Forest and cultivated cropland cover significantly decreased by 518 and 728 km^2, respectively. Most land cover change is accounted for in the upper Neuse hydrologic basin that includes rapidly growing areas in Wake, Durham and Johnston counties. Populations of counties that are wholly or partly contained within the basin increased by over 414,000 people between 1900 and 2000. Durham, Johnston and Wake are growing the fastest in the upper basin, with Pitt County growing the fastest in the lower basin. The county populations are expected to grow by more than 867,000 by 2020 from 2000 to almost three million people. With the increased population there will be increased drinking water demands and wastewater discharges. There will also be loss of natural areas and increases in impervious surfaces associated with construction of new homes and businesses. To achieve the goal of restoring impaired waters throughout the basin, the state government identified that the costs of restoration would be high, but identified several programs to provide funding for restoration efforts. These programs include the Clean Water Management Trust Fund, the NC Agricultural Cost Share Program, the Wetlands Restoration Program and the federally funded Conservation Reserve Enhancement Program. Although developed by the state, the plans provide minimal to no information on the specifics of recommended implementation activities and associated responsibilities. In actuality, the plan only provides general recommendations that are intended to be applicable to the entire state, not necessarily specific to Neuse Watershed and its stakeholders.

North Carolina's program was a holistic approach somewhat similar to the guidelines of developing watershed-based management plans by US EPA (US EPA, 2008), however it lacks key details, especially concerning coordination mechanisms and implementation strategies for the program. The planning process builds on rational and communicative approaches but offers no opportunities for sustained integrated stakeholder collaboration. The focus of the planning program was on gathering and disseminating scientific information about the river basins and involves the public on a little more than consulting level.

4. *Tapak River Water Management under PROPER program, Semarang, Central Java, Indonesia. (Primary Reference: Hoetomo, 2005)*

Indonesia launched several water management policies and programs for the compliance of Act No. 7 of 2004 on Water Resources Management and Government Regulation No. 82 of 2002 on Water Quality Management and Water Pollution Control. To promote environmental compliance, the government of Indonesia launched a program named *Program Peringkat Perusahaan* better known as PROPER. The program was an instrument to monitor environmental compliance and promote transparency by involving the public through formation of a council. The public council consists of representatives from academia, NGOs and international organizations that engaged in the process of defining environmental compliance performance ratings of industrial companies.

The rapid development of Semarang City and its surroundings, driven by its strategic location, caused population growth, the establishment of about 300-325 industries by 2012 and consequently deleterious impacts to Tapak River and its resources. The increasing population and industrial presence caused significant environmental impacts due in part to high reliance on groundwater as a water supply source obtained through deep wells or boreholes (Susanto and Putranto, 2018) as well as the use of river water polluted from industrial discharges, on rice fields (Hoetomo, 2005). The intense rate of development placed increasing demands on the environment including the depletion of limited water resources resulted in conflicts and disputes among various stakeholders. The mechanism of resolving or settling disputes was governed by the Environmental Dispute Settlement under the Environmental Management Act (EMA), Number 23 of 1997. EMA provides two alternatives mechanisms for the public to challenge environmental violations: in-court settlement (litigation process) or out-of-court settlement via the Alternative Dispute Resolution (ADR). In court dispute resolution was the conventional approach that typically consumed lengthy periods of time to settle cases. ADR is based on the voluntary participation of the parties involved in the dispute. In the early 1990s, Professor Emil Salim, the then Minister of the Environment and head of the Environmental Impact Management Agency (BAPEDAL) of the Republic of Indonesia, was committed to exploring ways in which ADR could be used to resolve specific contentious and difficult cases that remained unresolved while environmental conditions continued to worsen .

In 1990, a difficult dispute case, better known as the Tapak Case, took place in the city of Semarang within the province of central Java. The case pertained to the environmental pollution of the river brought about by ten companies located along the river bank and the use of this water for irrigation and found to adversely impact rice fields of surrounding communities. After a series of meetings conducted in the format of both face-to-face and private sessions, the parties reached an acceptable settlement. The resolution contained the provision of financial compensation by the companies to the local communities, the development of an environmental protection program, and pollution prevention initiatives. Irrespective of implementing the pollution prevention and protection program according to the settlement, the ADR approach demonstrated as an effective mechanism for resolution of the dispute settlement among the parties concerned. It encouraged both the government agencies and environmental NGOs jointly to choose the type of mechanism to settle similar disputes.

Capacity Analysis of International Top-Down Approach Examples

Four selected international examples were evaluated through SWOT, mainly focused on strength and weakness, to understand the merits and limitations to inform a new management framework that will integrate merits and to avoid limitations and weaknesses. Also, the cases were further evaluated to understand element or condition gaps that should be included in an institutional model for effective watershed management at watershed level. SWOT analysis focused on the capacity of each cases in delivering effective watershed management at watershed level towards addressing urban issues with at least the following necessary features:

- Government Support
- Local Knowledge and Local Actions.
- Engaging all Stakeholders in Decision Making.
- Decision Making at Watershed Level
- Interdisciplinary Approach
- Integrating Science, Policies and Regulations into Decision Making
- Funding

The outcome of SWOT analysis is presented in Table 3-1. Overall, each case analyzed revealed that there was a strong government program, voluntary or regulatory, that drove the top-down approach with the necessary support including funding, expertise, facilitation, coordination etc. Also, collectively this approach introduced new and efficient technologies and accomplished some stakeholder networking at local levels. However, the case approaches provided no institutional framework or arrangements to organize stakeholder engagement in the planning process. Almost in all cases, government developed plans included recommendations for local implementation without a delivery mechanism to support implementation activities at the local level. The challenges of implementing these plans and the lack of action revealed that an inequality in stakeholder participation during development of the plans was a major problem. Specifically, consideration of local input on stakes, knowledge, and impacts from local players was largely absent during development of the plans.

The lack of partnership between government and non-government participants resulted in challenges of bringing essential land owners and other stakeholders that needed to be involved in the process of implementing the recommendations of plans. Wherever stakeholders were actively involved through voluntary engagement, the outcome was more successful. Government mediation on the planning and implementation process helped in resolving disputes, however, inadequate capacity of stakeholders and the absence of an organized and impartial mediation hindered the implementation activities. The government's motivations failed to account for the motivations of other players, which ultimately precluded establishment of win-win partnerships. Consequently, this resulted in unsuccessful programs as non-governmental players avoided planning and implementation activities. The Green Revolution is a clear example that a foreign recipe with foreign ingredients is unsuitable for a local condition with totally different local ingredients. In this case, the local capacity was insufficient to critically evaluate the plan for suitability in meeting local needs and concerns. Followed by SWOT analysis, it was further examined that how the required major features for addressing urban issues at watershed level fared with the selected cases and presented in Table 3-2.

Table 3-1. Summary on SWOT analysis on the selected international top-down examples

	STRENGTH	WEAKNESS	OPPORTUNITY	THREATS
Lower Saxony Watershed Partnership GERMANY	- Government sponsored program - Government funding - Watershed management plan through scientific support - Continuous monitoring - Stakeholder meetings (Three Times per Year) - Systematic Approach to Control Agriculture Runoff - Local partners independently implemented some recommendation by themselves	- Top-down influence is exerted from state to local collaborative planning - No mechanism to implement recommended actions - Poor coordination among agencies challenged implementation - Land owners, major contributors of runoff issue, has shown less interest in collaboration - No interdisciplinary thinking in planning process - Unable to apply and secure government funds for implementation by local actors	- Local stakeholders have built a network independent from government formed partnership, but the collaboration was initiated by the planning process - Government has allocated funding to support local projects requests	- Several levels of Government Involvement and Disconnection Delayed Implementation - Government priorities impacted the resources, staff and fund, for implementation action
Punjab – India: Green Revolution Project INDIA	- Government sponsored program - Government and International aid funding - Government aid and subsidiaries for implementing new technologies - Economic growth - Produced 20% of the country's wheat and 12% of the rice on only 1.5% of the land	- Highest rate of groundwater depletion - Traditional ecology friendly farming system was destroyed by internationally sponsored high-yield, high-water demand, and high use of chemical approach. - Soil erosion, over use of pesticides, contaminated soil, loss of soil fertility, etc. - Non-availability of nutritious food for local consumption	- Introduction of new technologies on farming - Local network in learning and adopting new technology and receiving aid funds	- Complete loss of self-reliance and locally adoptive system - Invasion of foreign interests with short-sited technologies and expertise
Neuse River Watershed Planning USA	- Government sponsored program - Government funding - Watershed management plan through scientific support - Continuous monitoring - Systematic Approach to Control Agriculture and Urban Runoff	- No mechanism to implement recommended actions - Poor coordination among agencies - Many stakeholders unaware of planning process - No interdisciplinary thinking in planning process - Unable to apply for government funds for implementation by private citizen	- Partnership among state government and municipal government - Government has allocated funding to support local government for implementation	- Passive stakeholder engagement due to government dominance - Government priorities impacted the resources, staff and fund, for implementation
Tapak River Water Management	- Government sponsored program with tie to regulations and policies	- The role of government is too dominant - Lack of technical and regulatory skill of citizen participants	- Demonstrated the role of government as a new institutional setup	- Voluntary approach with no commitment

under PROPER program INDONESIA	- Government funding - Systematic and scientific approach - Government mediation - Stakeholder participation	- Land ownersand industrial partners not involved - Lack of implementation of pollution controls - Substantial delay in meeting schedule of implementation	- Coordination of Central and State Governments - Commitment to settle the dispute outside court	- Vulnerable for social, political and economic challenges
COMBINED TOP-DOWN CASES	- Government sponsored program - Government funding - Technical/scientific support - Continuous monitoring - Stakeholder meetings - Mediation	- The role of government is too dominant - No mechanism to implement recommended actions - Land owners and other major stakeholder haves shown less interest in collaboration - No interdisciplinary thinking in planning process - Unable to apply and secure government funds for implementation by local parties - Poor coordination among agencies - Many stakeholders unaware of planning process - Lack of technical and regulatory skill of citizen participants	- Government funding to support local projects requests - Introduction of new technologies - Local networks - Partnership among state government and municipal government - Demonstrated a new institutional setup - Commitment to settle disputes outside court	- Disconnection between different levels of government - Government priorities impacted the resources - Complete loss of self-reliance at local level - Passive stakeholder engagement due to government dominance - Vulnerable for social, political and economic challenges

Table 3-2. Comparison of top-down approach cases on the capacity of watershed management features.

Features for Sustainable Watershed Management at Watershed Level	**Lower Saxon, Germany**	**Green Revolution in Punjab, India**	**Neuse River Watershed, North Carolina, USA**	**Tapak River Case, Indonesia**
Government Policies and Programs	**Yes**	**Yes**	**Yes**	**Yes**
Government Support	**Yes**	**Yes**	**Yes**	**Yes**
Scientific/Expert Input	**Yes**	**Yes** (Ignored local expertise)	**Yes**	**Yes**
Funding – Government	**Yes**	**Yes**	**Yes**	**Yes**
Funding – Private	**No**	**Yes** (US based NGOs)	**No**	**Limited**
Local Action	**Limited**	**No**	**Limited**	**Yes**
Local Decision-Making	**No**	**No**	**No**	**Yes**
Local Collaboration	**Limited**	**No**	**Limited**	**Limited**
Local Knowledge	**Limited**	**No**	**No**	**Limited**
Land use/Urbanization Management	**No**	**No**	**Limited**	**Limited**
Integrated Actions Among Government Agencies	**No**	**No**	**No**	**No**
Institutional Arrangement to Link Government with Local Watershed Groups	**No**	**No**	**No**	**No**
Facilitation of Watershed Management and Decision Making	**No**	**No**	**Limited**	**Yes** (by Government)
Interdisciplinary Approach	**No**	**No**	**No**	**No**

Yes (Green) – Features identified as STRENGTH
Limited (Blue) – Features identified, but not functions for intended purpose
No (Red) – Features identified as WEAKNESS or not existed.

3.1.2 International Examples on Bottom-Up Approach

Four bottom-up approach case studies were identified and analyzed for strengths and weaknesses with a focus on identifying needed strengths and mechanisms to eliminate weakness for a new management framework for successful watershed management at watershed level.

1. ***Ohio Watershed Partnership, Ohio, USA (Primary Reference: Koontz and Newig 2014)***

The United States of America's. Clean Water Act of 1972 required all waters of the United States to attain "fishable" and "swimmable" status by 1983. As a result of failing to meet the target, in 1987, the federal statute was amended to promote community-based efforts to reduce nonpoint source pollution, often by developing and implementing watershed-based management plans (US EPA 1996, 2002, 2008).

In the state of Ohio, the state government encouraged watershed partnerships to develop watershed action plans. While state officials were available for consultation, they were not directly involved in decision making and the process of developing watershed action plans. However, the state gave the guidance for how to create a plan and whom to include in its development, recommending the inclusion of watershed residents, land owners, businesses, community organizations, educational institutions, and state and local governments. State program officers engaged with partnerships throughout the process, often suggesting specific stakeholders to engage based on the availability of resources or being community leaders. Ohio had a mechanism to fund local watershed partnerships in their planning efforts. The Ohio Watershed Coordinator Grant Program gave selected partnerships $35,000 per year to hire a coordinator to develop an action plan. Grant recipients received funding, training, and guidance, but they were not led by state government officials. Rather, they were led by soil and water conservation districts, non-profit organizations, local governments, or regional planning agencies. In addition, the state programs allocated funds to promote implementation. Not all watershed partnerships in Ohio received funding from the government. Only partnerships with action plans endorsed by the state were eligible to receive these funds. In evaluating plans for endorsement, state officials considered the degree to which a plan met content guidelines specified in the state's watershed management programs and policies and designed to address watershed boundaries, stakeholders, biophysical characteristics, land use, impairments, restoration goals, implementation, and evaluation.

The process of plan development was conducted through a bottom-up approach. Although guidance was given from the state agency managing the program (Ohio Department of Natural Resources), local communities initiated the planning process, apply for funding, and led the efforts. Subsequently, the created plans were submitted to the state agency where it was given serious consideration and if endorsed a plan became an important document to guide implementation and unlock resources for implementation from the state. However, the state was not in charge of the implementation (Figure 3-2).

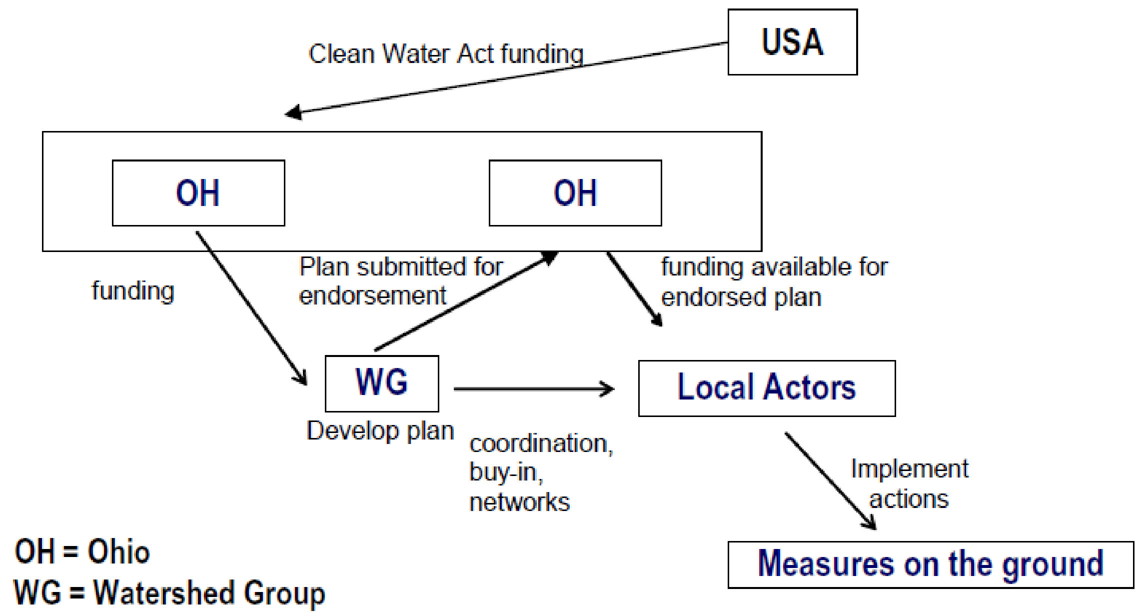

Figure 3-2. Bottom-up watershed planning in the state of Ohio, USA (Adopted from Koontz and Newig, 2014)

Overall, Ohio's program was somewhat successful and resulted in several valuable lessons learned. Among the three cases evaluated by Koontz and Newig (2014), one group reported not only developing a successful plan, but also had actively implemented many watershed action plan recommendations. The group's Progress Review Report for 2011 indicated on-the-ground actions such as stream clean-ups, slag leach bed installations, grass plantings, and the covering of toxic mine spoils. The success of this effort is attributed to stakeholder collaboration, receiving support from the government on funding and technical guidance, and full-time coordinator.

In the second case, the group described implementation challenges due to lack of resources especially relating to not hiring a full-time watershed coordinator for implementation actions. Another notable hindrance to this group was that the state government cut the funding in the middle of the process. Local opposition and stakeholder conflicts also hindered progress on implementation. For example, the plan recommended removal of a low-head dam. However, when it was ready to be implemented after securing the funding, a section of stakeholders opposed its removal because they feared flooding or other issues downstream. Those in opposition did not fully understand the technical basis that supported the project, possibly because of inadequate communication and facilitation among key stakeholders. As a result, the project was never implemented.

The third case group's experience was somewhat successful, similar to, the overall state's program. The plan developed by this group was only conditionally endorsed by the state government due to the plan not being fully in line with government programs and policies. The group's Progress Review Report for 2011 indicated on-the-ground actions such as invasive species removal, riparian vegetation plantings, streambank restoration, and in-stream habitat structure installations. Due to receiving the endorsement, the group had the advantage of funding for a watershed coordinator to promote implementation.

Overall, the Ohio cases with higher member perceptions indicated that their collaborative efforts led to improved implementation and environmental conditions. This improved outcome is attributed more robust stakeholder participation with adequate resources, dedicated leaders, willing land owners, and networks rather than a top-down vs. bottom-up approach. The collaborative planning generated from local participants and organizations, and the resulting plan was passed up to the state government, where it was carefully scrutinized. Upon endorsement, the watershed became eligible for various grants to carry out recommended actions. In addition, the state agency provided funds for some groups to hire full-time watershed coordinators and those groups tends to report success in implementation.

2. ***Water Watchers, Kwinana WA, Australia (Primary Reference: Carr, 2002)***

Water Watchers (WW) was formed in Kwinana, Western Australia located south of Perth by local residents in response to concerns of being labelled as the perpetrators of environmental destruction. The local residents were blamed for contributing toxic levels of phosphates to the waterways which in turn were causing outbreaks of blue-green algae blooms in a suburban estuarine inlet. The members started monitoring phosphate levels in creeks, streams and drains within their community in response to their perception of blame from the government. WW members had a strong social network within the community and similar to other stewardship groups exhibited interdependency between protection of waterways and their sense of community. Figure 3-3 identifies the other community groups that WW members either participated in or interacted with as part of WW activities. The nine circles below the oval are other community groups in which WW members had participation. Generally, there was little overlap between members belonging to the other community groups. Above the WW oval are other organizations to which WW's maintained formal relationships. The WW group was a subcommittee of the Local Conservation District Committee, an organization of local landlords, who were the umbrella group responsible for accounts and submissions. They were linked to the Serpentine Jarrahdale Shire Council which strongly supported the group via provision of in-kind resources and a venue for meetings. The Shire Council also had strong ties with the Community Catchment Center which provided facilitation to the group. At the top of the figure, the Serpentine Jarrahdale Ratepayers Association was linked to the Shire and was also linked to WW with several members in common in the two groups.

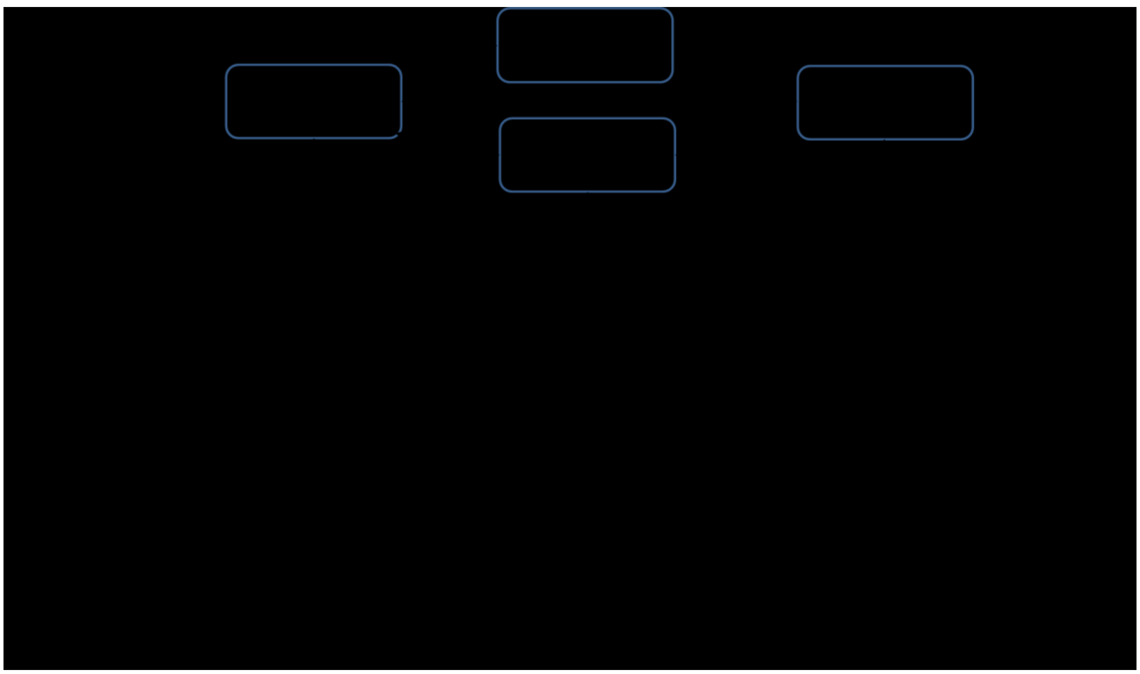

Figure 3-3. Bottom-up watershed planning of Water Watchers, Kwinana WA, Australia (Adopted from Carr 2002)

Among their achievements, WW was one of the first community groups to produce water quality data suitable for inclusion into government databases. In Western Australia their effort toward integrated watershed management have been recognized by two Ministers of Parliament. WW received a great deal of support and advice from the Community Catchment Centre established and funded by government and based nearby in Pinjarra.

WW started out strongly with a well-defined and locally active constituency. The group achieved their primary goal of continuously monitoring local water quality over three consecutive years and proved that the governments blame on local landowners was misplaced. However, their watershed protection and planning activities that went beyond water quality monitoring soon fell apart once a couple of key members had left the group to pursue other commitments.

3. *Punjab Rural Water Supply, Pakistan (Primary References: Smith 2008, Asian Development Bank 2009, World Bank 2018)*

Up until the early 2000s, women and female children of the Pakistani province of Punjab would commonly spend up to 5–6 hours a day collecting their water for domestic use from distant ponds, rivers, canals and uncovered wells commonly used by animals. These sources were usually brackish, fecally contaminated, odorous and infested with disease-bearing insects. Daily consumption of this dirty water had caused many diarrhea-based illnesses such as cholera and malarial infections to become widespread through the insect infestation. Children were the most vulnerable to contraction of illnesses and infections and were the most vulnerable to fatal outcomes. The government of Pakistan was concerned about this lack of safe water supply, so with funding from the Asian Development Bank (ADB) the Punjab Rural Water Supply Sanitation Sector Project was initiated.

This project was the first participatory-based water management project in Punjab, in which the design and construction of wells and water supply distribution systems were completed according to local community input. Across 335 remote and mostly poor Punjabi villages, community-based organizations (CBOs) were formed to define and organize their specific community needs, wants and aims in relation to local water access and management. This project not only resulted in an additional 800,000 more people having access to safe water supplies, but it also provided capacity-building and empowerment opportunities. Not only were local people participating in the initial planning and construction stages, but operation and maintenance responsibilities of the project were eventually devolved to local participant communities throughout the province following training in supervisory skills tariff collection, financial management, technical operations and water quality monitoring. With women now liberated from the time consuming and physically exhausting water-gathering duties far from their village, average household incomes in the province rose by 24% because women had more time for entrepreneurial pursuits such as making clothes and handicrafts to sell for income. School enrolments also increased by up to 80% as more young girls now have time to attend. In one village, some women set up a small school for girls (employing two female teachers) while others helped set up a corner grocery store and a local flour mill. There was also a general increase in ecosystem health throughout the province, with notable decreases in odors and insect infestations due to increased community environmental stewardship. The improved environmental conditions have led to a general increase in health and well-being throughout the province, with fewer sick days being reported and a 90% reduction in harmful waterborne disease occurrences.

All information provided on Punjab case was presented by Smith (2008) citing the reporting by ADB in the World Water Forum in 2003. However, five years after initial reporting on the success and after operation and maintenance efforts were well underway by CBOs and the Pakistan Government, the outcome was determined to be less successful than originally determined at the time of the initial reporting. Still, ADB (2009) rated the overall performance of ADB's assistance to rural water supply in Pakistan's Punjab Province as successful but at the lower end of the scale. This was based on the assessments reported in the project completion reports of the two projects, and validation by the Independent Evaluation Department of the Punjab Community Water Supply and Sanitation (Sector) Project (PCWSSP) completion report. Collectively, the projects had positive impacts on local communities and people that likely to be sustained with adequate technical support and trainings to strengthen capacity of the CBOs responsible for managing respective subprojects. Some of the major concerns were:

1. 20% of the subprojects were non-functional;
2. Only 43% of CBOs responsible for subprojects were functional;
3. Cost recovery and capital replacement mechanisms were not built-in;
4. High fuel and electricity costs, and erratic power supply had potential to halt operational subprojects;
5. CBO capacities remains weak;
6. Government commitment for continuing support for subprojects was weak;
7. Participation of poor remained low due to meeting upfront cash requirements; and
8. Operational link between the Public Health Engineering Department and the tehsil municipal administrations remained very weak.

This project provides an excellent example of donor-based or international development assistance-based activities and their impacts following implementation in developing countries. Although the bottom-up approach was successful, the continuation of implementation support to sustain the success was weakened by inadequate government support and resources and the limited capacity of CBOs. Recently, World Bank (2018) approved US $ 2 billion assistance for similar effort to same Punjab Region in Pakistan.

4. *Mae Sa Watershed, Thailand (Primary Reference: Heyd and Neef, 2004)*

The Mae Sa watershed case is representative of a small-scale commercial and agriculture watershed with a high degree of stakeholder complexity. Stakeholders include upstream and downstream communities, tourist resorts, drinking water companies, and several government agencies. Some subunits of government agencies are even located in the watershed while the line departments of the district and province administration are in Chiang Mai. Further, the watershed had been selected to serve as a pilot project for river rehabilitation launched by the Prime Minister in December 2003. The Mae Sa stream flows into Mae Ping, which is one of the main tributaries of the Chao Phraya River, whose delta constitutes Thailand's 'rice bowl'. The Mae Sa watershed includes the area from the source of Mae Sa stream until the outlet into the Ping River including all the streams and creeks flowing into Mae Sa, which is an area of 142.2 square kilometers. Droughts in the dry season threaten village water supplies for domestic and irrigation uses. The local people dealt with growing water problems in their villages through uniquely established water supply systems. Over the years, every village had developed its own management system. The water in villages, a common pool resource, was not under an open access regime as it was mistakenly thought to be by some government agencies. Instead the property regimes of the water in the villages was subject to different tenure regimes and determined by a range of local factors such as power structures, kinship relations, geographic conditions, technical choices, and socio-economic settings in the villages. Management systems at group and communal level were often able to deal with water allocation in an efficient way, but they did not necessarily provide the fairest or most sustainable form of water governance. The people and organizations that had an interest in water issues in the Mae Sa watershed can be divided into five stakeholder groups:

1. local people upstream, living in seven communities,
2. local people downstream (17 villages),
3. enterprises (20, mostly tourist resorts),
4. research organizations (Watershed Research Institute, The Uplands Program, Chiang Mai University, Mae Jo University), and
5. government line agencies (under the Ministry of Natural Resources and Environment and the Ministry of Agriculture and Cooperatives).

Thailand, a traditionally centralized government, has made attempts to devolve power to lower (local) levels in the 1990s through the establishment of the Tambon Administrative Organizations (TAOs) and the recent People's Constitution. In the 1997 Constitution local administrative units such as the TAOs and individuals were given the right to participate in the management of natural resources. Moreover, the line departments at the district and provincial levels had been given orders to apply participatory policies in water resource management. Certain participatory projects had been included in the plans of the departments at the local level. The case study from the Mae Sa watershed demonstrated that it was not enough to put participation on the political agenda or give orders about implementation. Hyde and Need (2004) gave the following recommendations after observing the symbolic participation (tokenistic) of local people.

1. The involvement of local people in the political process and in research and development requires more fundamental changes in the structure of the government agencies and among their staff.
2. Government officers need to change their attitudes towards local people and learn that participation was not only a tool to improve project outcomes, but also a worthwhile objective in itself.
3. The universities and schools - where the government officers receive their technical education in e.g. engineering, forestry or agriculture - need to extend their curricula by modules on participatory research and development.
4. Further, seminars and trainings that provide the necessary communication and facilitation skills for working with local people should be offered for the government staff already in office.
5. Reducing the mistrust between government officials and local people is certainly a long process but could be facilitated through the establishment of pilot sites where the success of cooperation between government officers and local people is demonstrated as exemplified by the case of the Mae Ta Chang watershed.

The example from Mae Sa watershed shows that participatory water management in Thailand was a good theoretical concept but in practice it required a lot of fundamental changes for it to be effective. Hyde and Neef (2004) stated that "the government has yet to demonstrate that its openness to participatory approaches is more than just another populist political strategy." But the government officers were not prepared to really involve the people in joint decision making and the departments were not ready to release power to the local people. This especially applies to the conservation-oriented government organizations such as the National Parks, Plant and Wildlife

Department, which were reluctant to yield responsibility over resource conservation to local people who they thought would exploit the resources. In the development-oriented departments, some officers with closer contact to the public would try to apply participatory approaches but they often lacked both the necessary skills and the support from their superiors to really engage in a collaborative process with local people.

Accordingly, changes in the government agencies were hardly noticeable at the village level, at which it was barely noticeable that possibilities for participation had improved. The local public continued to have a negative impression of government officers and continued to rely on local methods for water management instead of contacting the government agencies for help. However, local people did perceive the involvement of the TAO and the occurrence of a larger number of meetings and committees to which only politically influential people like the village headmen or TAO representatives were invited. Among these more influential stakeholders, the perception of change was different. Because of their closer contact with the government agencies, they perceived policy changes towards more involvement of the public.

Nevertheless, the policies were still not enough for them and appear to the local elites rather as a justification for the preconceived actions of the agencies. Taking Pretty's classification as a reference, participation occurs, if local people were being involved at all, only as passive participation, in information giving, rarely by consultation, and in the case of the Office of Highland Development, for material benefits. In communities covered by the Royal Project, people were being consulted, and even the Royal Irrigation Department (RID) sometimes asked local people about their priorities. However, final choices were ultimately made by the still being made in the government agencies in isolation, so in actuality local people had neither real decision making power nor institutionalized opportunities to participate in the decision making process for the management of local resources. Thailand's constitutional right for participation in resource management was not sufficiently put into practice at an effective level where participation by all stakeholders involves constructive collaboration and a negotiation process for collectively finding balanced solutions that considered all stakeholder interests. This case illustrates that effective participation was far from being reached for local water issues in Thailand.

Capacity Analysis of International Bottom-Up Approach Examples

Similar to the analysis of top-down examples, four selected international examples were evaluated through a SWOT analysis, mainly focused on strength and weakness, to understand the merits and limitations for informing the development of a new management framework by integrating merits and to avoid limiting conditions. Also, the cases are further evaluated to identify apparent element gaps that would likely be important for developing an institutional model for effective watershed management at the watershed level.

The outcome of SWOT analysis is summarized in Table 3-3. Unlike the cases evaluated for top-down approach in which strong government programs were the primary driver of the process, there was substantially more variability among the selected bottom-up cases reviewed. Water Watchers, Australia is purely driven by local residents' interest in local water issues. It has no connection with regional or national interests. Mae Sa, Thailand is a bottom-up approach that was purely driven by government agencies. In a way, it could be described as a top-down approach with an apparent bottom-up framework. Punjab, Pakistan provides a good example of well-coordinated, institutionalized and facilitated bottom-up approach with government and ADB support that resulted in successful outcomes. However, it is a typical example of international funded projects and programs in which the developing world beneficiaries struggle to sustain programs after their initial implementation. Ohio, USA example is a good example of a bottom-up approach involving local participation in a facilitated collaborative planning process that resulted in successful implementation of recommendations from the planning process. However, it is important to note that there was no successful case reported in Ohio without government support and endorsement, although the planning is purely through a bottom-up approach. In general, the success of bottom-up cases evaluated can be attributed to: Strong local participation involving collaboration, engagement and networking among a diverse mix of stakeholders; Local capacity on technical and financial resources; Adequate facilitation of the decision making and planning process; and government support/endorsement. Except Mae Sa, Thailand, the local collaboration, stakeholder engagement and partnership were active and motivated by factors that resonated locally. For example, Water Watchers have expressed emotional attachment to the issue being addressed (Carr, 2002). In Mae Sa, the collaboration and partnership were influenced by government and became passive for local people. In Punjab, Pakistan case, there are certain sector of stakeholders that had been excluded. However, the participants were actively engaged in the project because they were motivated by a single goal of safe drinking water and safe disposal of wastewater.

Based on the SWOT analysis, required major features for effectively addressing urban issues at the watershed level were identified and are presented in Table 3-4.

Table 3-3. Summary on SWOT analysis on the selected international top-down examples

	STRENGTH	WEAKNESS	OPPORTUNITY	THREATS
Ohio Watershed Partnership USA	- Local led planning - Collaborative process - Willing landowners allowed implementation in their properties - Strong local networking - Stakeholder engaged decision making - Government support, funding and technical	- Success varies group to group - No success reported without government support - Limited capacity of local stakeholders in implementing plan - Stakeholder conflicts resulted in abandoning recommendations from plan - No interdisciplinary thinking in planning process - Only focused on agricultural runoff pollution	- Strong local network with government endorsement that has the potential for interdisciplinary approach - Multiple sources of government funding	- Government priorities impacted the resources, staff and fund, for implementation action - Long-term sustainability rely on the partnership of landowners and government
Water Watchers AUSTRALIA	- Local grown planning - Collaborative process - Strong local network - Stakeholder engaged decision making - Membership based funding - In-kind support from local government	- Only focused on algae bloom issue - Limited capacity on technical and funding resources - Once a couple of key members left, the process collapsed - No systematic organization or facilitation of planning process	- Strong network that led to collaborative watershed programs and approach in Western Australia - Government endorsement	- Isolated effort so that no connection with regional and national effort - No replication of lesson learnt
Punjab - Pakistan Rural Water Supply PAKISTAN	- Government sponsored program - ADB funding - Watershed management plan through scientific support - Local decision making - Collaborative effort - Capacity building through training and enforcing locals - Organized facilitation	- No mechanism to sustain after completion of project - Limited capacity of local to maintain the institutional and physical infrastructures - Poor organization and planning in revenue collection that resulted in abandoning resource - No representation of economically disadvantage people who are supposed to benefit	- Safe drinking water and disease prevention - Technical and organizational capacity building	- Loss of local adaptation due to foreign induced plans - Global petroleum price have direct impact
Mae Sa Watershed THAILAND	- Government sponsored program - Systematic and scientific approach - Government mediation	- The role of government is too dominant - Lack of technical and regulatory skill of citizen participant - Only influential people of community represented	- Theoretically sound bottom-up approach - Tie to government regulation, policy and programs	- Vulnerable for social, political and economic changes - Success rely on overall attitude change of

	- Multiple stakeholder participation - Institutional setup for participation and facilitation	- Challenges in implementation activities due to passive local collaboration - No mechanism to resolve differences opinions - No mechanism and organization to sustain	- Availability of government funding	government staff in devolving power to grass-root
COMBINED BOTTOM-UP CASES	- Local led planning - Collaborative process - Willing landowners allowed implementation in their properties - Strong local networking - Stakeholder engaged decision making - Government support, funding and technical - Watershed management plan through scientific support - Capacity building through training and enforcing locals - Organized facilitation - Institutional setup for participation and facilitation	- No success reported without government support - Limited capacity on resources and skills - Stakeholder conflicts resulted in abandoning recommendations from plan - No interdisciplinary thinking in planning process - No mechanism to sustain the process - No systematic organization or facilitation of planning process - No representation of diverse stakeholders - The role of government is too dominant - Challenges in implementation activities due to passive local collaboration - No mechanism to resolve differences of opinions	- Strong local network with government endorsement that has the potential for interdisciplinary approach - Multiple sources of government funding - Technical and organizational capacity building - Theoretically sound bottom-up approach - Tie to government regulation, policy and programs	- Government priorities impacted the resources - Long-term sustainability rely on the partnership of government and non-government - No replication of lesson learnt - Vulnerable for social, political and economic changes - Overall attitude change of government staff in devolving power to grass-root

Table 3-4. Comparison of bottom-up approach cases on the capacity of watershed management features.

Features for Sustainable Watershed Management at Watershed Level	Ohio Watershed Partnership, USA	Water Watchers, AUSTRALIA	Punjab Rural Water Supply, PAKISTAN	Mae Sa Watershed, THAILAND
Government Policies and Programs	**Yes** (No direct involvement)	**No**	**Yes**	**Yes**
Government Support	**Yes**	**Yes**	**Yes**	**Yes**
Scientific/Expert Input	**Limited**	**No**	**Yes**	**Yes**
Funding – Government	**Yes**	**No**	**Yes** (Asian Development Bank)	**Yes**
Funding – Private	**Yes**	**Yes**	**No**	**No**
Local Action	**Yes**	**Yes**	**Yes**	**Limited**
Local Decision-Making	**Yes**	**Yes**	**Yes**	**Limited**
Local Collaboration	**Yes**	**Yes**	**Yes**	**Limited**
Local Knowledge	**Yes**	**Yes**	**Yes**	**Limited**
Land use/Urbanization Management	**No**	**No**	**No**	**Limited**
Integrated Actions Among Government Agencies	**No**	**No**	**No**	**No**
Institutional Arrangement to Link Government with Local Watershed Groups	**Limited**	**No**	**Yes**	**No**
Facilitation of Watershed Management and Decision Making	**Limited**	**Yes**	**Yes**	**Limited**
Interdisciplinary Approach	**No**	**No**	**No**	**No**

Yes (Green) – Features identified as STRENGTH
Limited (Blue) – Features identified, but not functions for intended purpose
No (Red) – Features identified as WEAKNESS or not existed.

3.1.3 Formulating Framework by Integrating both Top-Down and Bottom-Up Features

The overall conceptual design and primary features of the new framework are shown in Figure 3-4 below. The institutional capacity requires many features ranging from government policy and resources from the top to local action by local stakeholders at the bottom. Government policy, program and funding with technical expertise, local collaboration, and the local knowledge need to be appropriately linked for addressing the multi-disciplinary watershed issues. These are essential components of an interdisciplinary approach and a self-sustaining institutional framework designed for sustainable watershed management. As such, government agencies (all involved) at different levels (federal, state or prefectural, and local), non-governmental organizations (NGOs), watershed groups, and private stakeholders are essential to the framework in recognition of their key role in adequately addressing many complex watershed-related environmental issues.

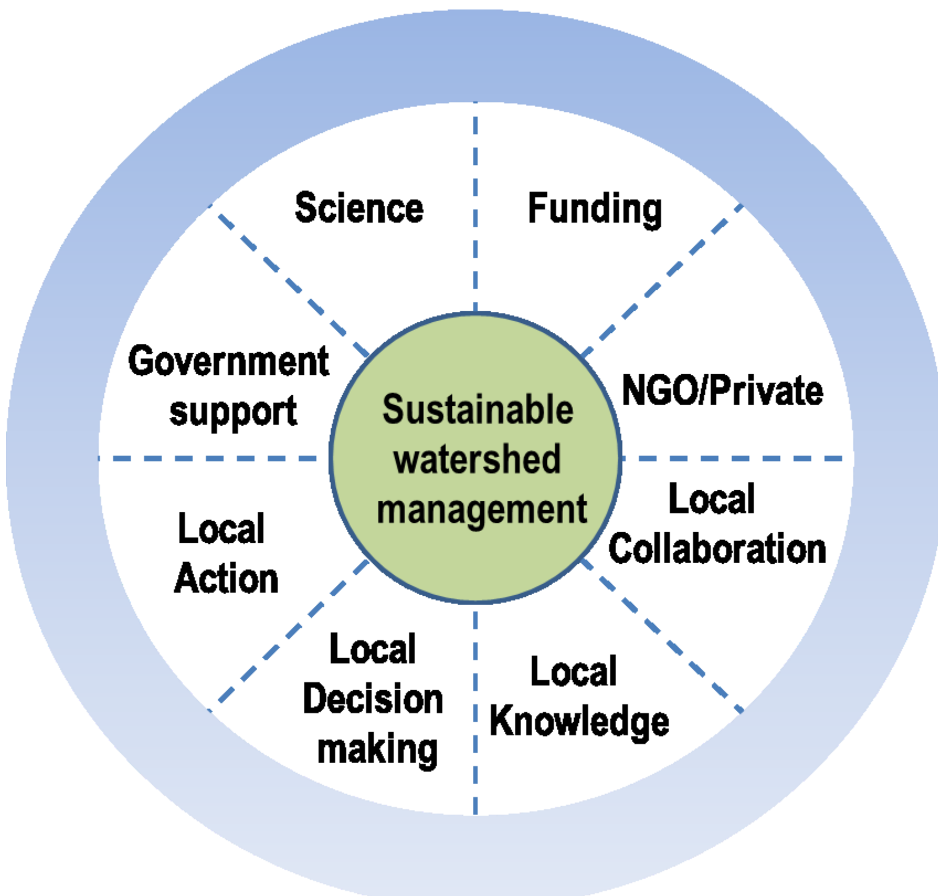

Figure 3-4. Conceptual design of the new management framework for sustainable watershed management. The framework promotes and sustains effective integration of the technical expertise, and governmental programs, polices and funding with local knowledge, collaboration, decision making, and actions.

Recognition of the inherent challenges associated with effective watershed management at local levels is first needed to justify bringing external funding and technical support resources to the framework table. Resources from government agencies, academic institutions and donor agencies are generally needed to successfully address multi-disciplinary local issues through a local decision making process with inclusion of all stakeholders. As the figure illustrates, the ultimate goal of this framework is to achieve sustainable watershed management while allowing urbanization to proceed but with mitigating measures to address water resources impacts such as flooding, excessive low flows, groundwater depletion, water pollution, and habitat and aquatic life destruction, etc. Towards this goal, the framework needs to be formulated by integrating capacities that can effectively address these issues.

It is important to note that the case reviews revealed that it is more important to focus on identifying those features and characteristics that are needed for an effective framework rather than attempting to follow either a top-down or bottom-up approach. As demonstrated in the previous sections, there are bottom-up approaches with the characteristics of top-down and vise-versa. Overall, the top-down's strength is government policy, program, and technical and funding support. In the meantime, the dominance of government influence is identified as weakness of both top-down and bottom-up approaches that resulted in passive or symbolic participation of stakeholders. Local collaboration, local stakeholder engagement and local decision making are considered as strengths of bottom-up approaches while the same are considered weaknesses of the top-down approaches.

The successful plans, reported in the cases evaluated, were developed and implemented by engaging all stakeholders at the local level with government support for resources and guidance on understanding applicable policies and regulations. Therefore, it is important to have an arrangement that includes government involvement with an appropriate balance of influence so that the non-governmental stakeholders are fully engaged with a sense that their contributions are equally valued in the process. An effective participation process also helps to eliminate the mistrust of the government by local stakeholders, as reported in one case in Ohio, USA and Mae Sa, Thailand. While mediation and facilitation are considered as strengths of both approaches, the lack of facilitation is considered a critical weakness for the bottom-up approach. In a detailed look at the cases which reported mediation/facilitation as a strength, it revealed that the facilitation was done through a systematic and professional way where the mediator plays an impartial or neutral role. In Ohio, USA and Indonesia cases, it was reported that the success was attributed to professional mediators with a neutral role. However, Mae Sa, Thailand, is an example that government biased facilitation made local stakeholders become unengaged or, at best participate passively. While facilitation is to move the process of planning and implementing in a systematic and professional way, it is important to maintain the right balance of stakeholder participation when the decisions are being made. In Lower Saxony, Germany, the meetings were held three times per year that helped to maintain a level of continuous participation.

The strengths and weakness of top-down and bottom-up approaches identified from the case analyses are identified in Figure 3-5. This summary provides the means for integrating strengths and elements to avoid weaknesses into the framework

TOP-DOWN		BOTTOM-UP
• Government sponsored program • Government funding • Technical/scientific support • Continuous monitoring • Stakeholder meetings • Mediation STRENGTH		• Local led planning • Collaborative process • Willing landowners allowed implementation in their properties • Strong local networking • Stakeholder engaged decision making • Government support, funding and technical • Watershed management plan through scientific support • Capacity building through training and enforcing locals • Organized facilitation • Institutional setup for participation and facilitation STRENGTH
	INTEGRATING LINKS: Common Platform Partnership Facilitation	
• The role of government is too dominant • No mechanism to implement recommended actions • Local players less interest in collaboration • No interdisciplinary thinking in planning process • Inability of locals in secure government funds • Poor coordination among agencies • Many stakeholders unaware of planning process • Lack of technical and regulatory skills WEAKNESS		• No success reported without government support • Limited capacity on resources and skills • Stakeholder conflicts resulted in abandoning recommendations from plan • No interdisciplinary thinking in planning process • No mechanism to sustain the process • No systematic organization or facilitation of planning process • No representation of diverse stakeholders • The role of government is too dominant • Challenges in implementation activities due to passive local collaboration • No mechanism to resolve differences of opinions WEAKNESS

Figure 3-5. Concept of management framework in integrating both top-down and bottom-up approaches through three elements, common platform, partnership, and facilitation.

The first and foremost component of the new management framework is a **common platform** where all parties convene. Also, it serves as the institutional set up for the process of effective watershed planning and management through active participation by all stakeholders. The call for establishing this platform should come from the top, (i.e., government) preferably, because of its foundational policies and programs related to watershed management issues. In this way, the government action solidifies the formation of the process with recognition of its need and its essential support to provide the institutional arrangement.

The platform will ensure that all parties maintain meaningful involvement in the decision-making process. This means that each party not only receives the invitation to participate, but also utilizes the platform for careful deliberation and for sharing and implementing the results of technical analysis (Hammond, 1999). Under the new framework, this platform will play a key role in bringing a Collaborated, Committed, and Continued (3C) approach of stakeholders to address the issues related to land use change and urbanization. Government agencies, NGOs, grass-root level organizations, and private citizens can also actively participate and contribute to the watershed management processes through the platform.

A second key component of the framework is the identification and involvement of the **partnership** from all major groups at the watershed. It is important to note that building the partnership is one of the very first steps that is recommended by the United States Environmental Protection Agency (US EPA) in the recommendation of developing watershed management plans (US EPA, 2008). In general, one will find at least the two major groups of the stakeholders in a watershed (Kontogianni et al., 2005). The first group is composed of private residents, environmental stewards, watershed groups, non-governmental organizations and local legislators and politicians. Impacts or issues, such as flooding, drought and/or water quality related in the watershed typically motivate this group to participate because of how these issues tend to directly or indirectly impact their lives, functions and or responsibilities. The second group is composed of local, state, and government employees, who are often responsible to implement and enforce applicable regulations. This group could also include academics and/or experts. This group is mainly motivated through regulations and job functions. Participation of the first group is extremely important for identifying and recognizing issues that threaten the waterbodies. The first group also generates the momentum to garner attention from political and governmental higher ups that likely be needed to support appropriate decision-making in new regulations, policies and funding mechanisms at local and federal levels. The participation of the second group is equally important for enforcing regulations and policies and carrying out necessary actions to address the issues. As shown in Figure 3-6, the partnership of these two groups, who are differently motivated, towards the same goal of protecting and restoring the watershed is vital towards sustainable watershed management.

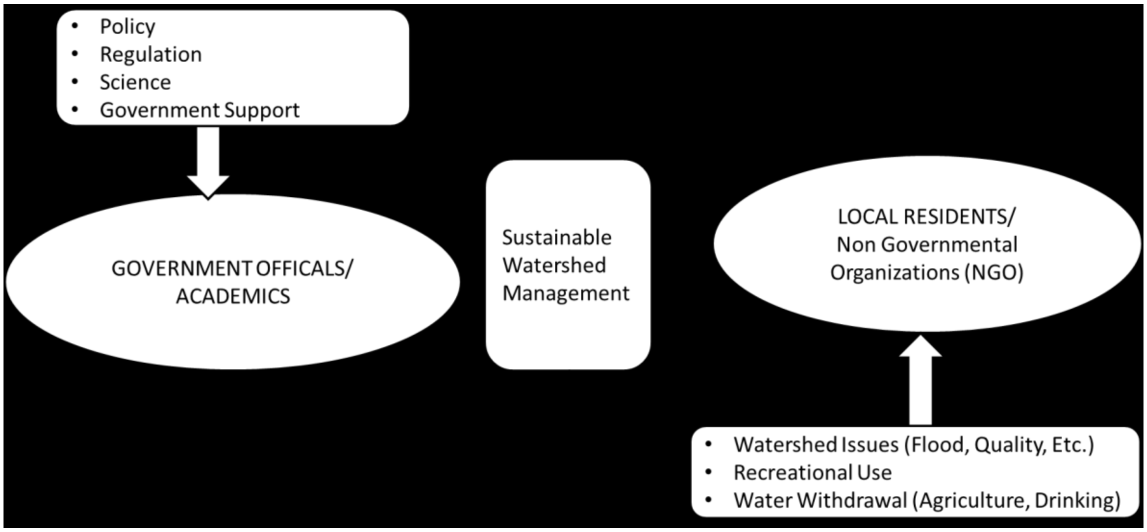

Figure 3-6. Linkage of the partnership from stakeholders motivated by issues with policies, regulations, and job functions in the new management framework.

A third key component of the new management framework is the mechanism for **effective facilitation** among the parties. A successful watershed management program can only be sustained through appropriately facilitating differently motivated stakeholders toward a common goal, addressing the issues to protect and restore the waterbodies. Organizational and functional structures have to accommodate the exchange of ideas and to encourage democratically acceptable decision-making. One major format of facilitation are regular meetings, which can be either quarterly or monthly meetings. Regular meetings are crucial for maintaining a dynamic and vibrant water management planning and decision-making process. The planning process is iterative, holistic, geographically defined, integrated, and collaborative (US EPA, 2008).

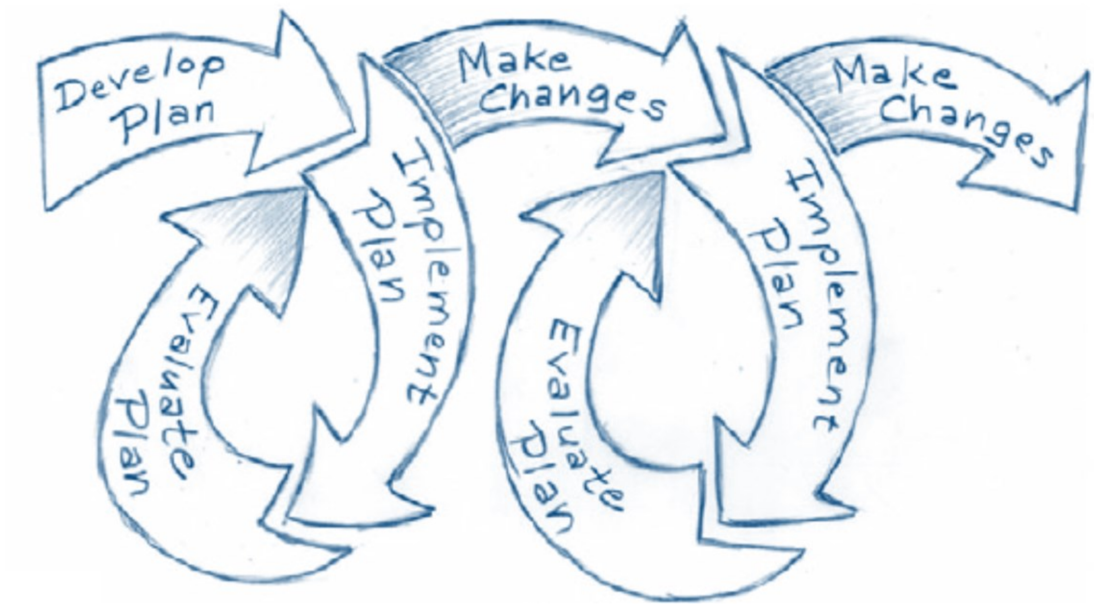

Figure 3-7. Iterative nature of watershed planning might take several cycles to effectively address and resolve selected watershed issues (Adopted from US EPA, 2008).

Although it is iterative (as shown in Figure 3-7), different issues might require specific steps, in general, systematic steps (Figure 3-8) in each cycle can be applied to address water related issues in a watershed. As shown, the steps should include, at minimum, problem identification, problem recognition, problem investigation for implementation planning, and problem solving through collaboration involving the constructive exchange of ideas among stakeholders, and finally though implementing actions. These four steps align with the tasks recommended by US EPA in developing watershed management plans and TMDLs (US EPA, 2008).

Although the cycle is fundamentally similar to the well-known Deming's Plan-Do-Check-Act (PDCA) model used in industrial process applications, this framework focuses on issues associated with natural resources management that involves complex interactions of numerous and highly variable factors that require long term continuing attention and evaluation.. Thus, it includes one or more internal PDCA cycle(s) in every step. Problem identification step involves the process of detecting an issue that needs attention so that it can ultimately be addressed. For example, conducting a screening level water quality sample collection under problem identification is part of planning stage of a large PDCA cycle of watershed management. However, sample collection itself includes another internal PDCA cycle of developing a sample collection plan, executing it, checking and adopting needed changes, and implement it until it reaches to the level of identifying the issue. The Framework includes similarity with other PDCA steps; Problem Recognition - the process of working with all stakeholders to understand and hopefully accept the issue with a commitment towards issue resolution; Problem Investigation/Implementation Planning - the process of evaluating and recommending clear remedial and implementation actions; and Problem Solving/Implementing Action - the process of executing the remedial or preventing actions to solve the issue.

The framework also requires integrating related regulations and stakeholder participation into the decision makings at every step. As a result, the four major steps are intended to address water resource management issues for the long term into the future with appropriate integration of stakeholder involvement. While the four components represent individual phases of solving water related issues in a watershed, the regular meetings are the bond to link one component to another and to continually advance a well-informed decision-making process with full stakeholder participation. Through this cycle, priority issues can be continuously identified and addressed through the 3C approach that is core to the new management framework. The new framework could be viewed as the base (permanent platform), the pillar (facilitation), and the beam (partnership) of the structure of a pendulum balance that is used to weigh things (Figure 3-9). The framework provides the structure and process to conduct the **balancing** act of bringing **external support** (through government programs and funding and scientific resources) to addressing **local issues** through appropriate decision making by the stakeholders at watershed level towards sustainable watershed management.

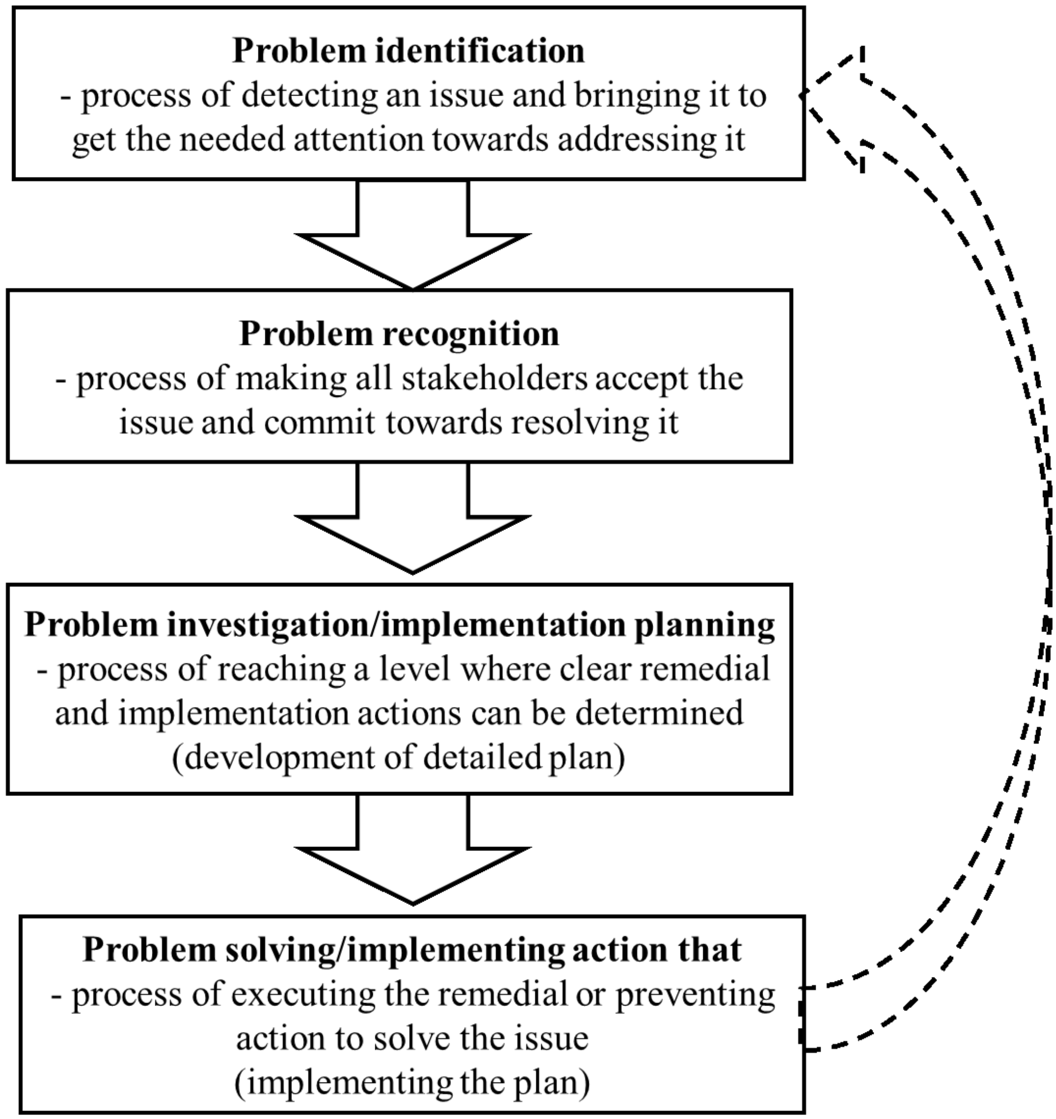

Figure 3-8. Four steps in a systematic cyclic approach to address the issues under the new management framework. Each step may include one or more internal Plan-Do-Check-Act cycle(s). The cycle will go on and on until the issue is fully addressed and resolved.

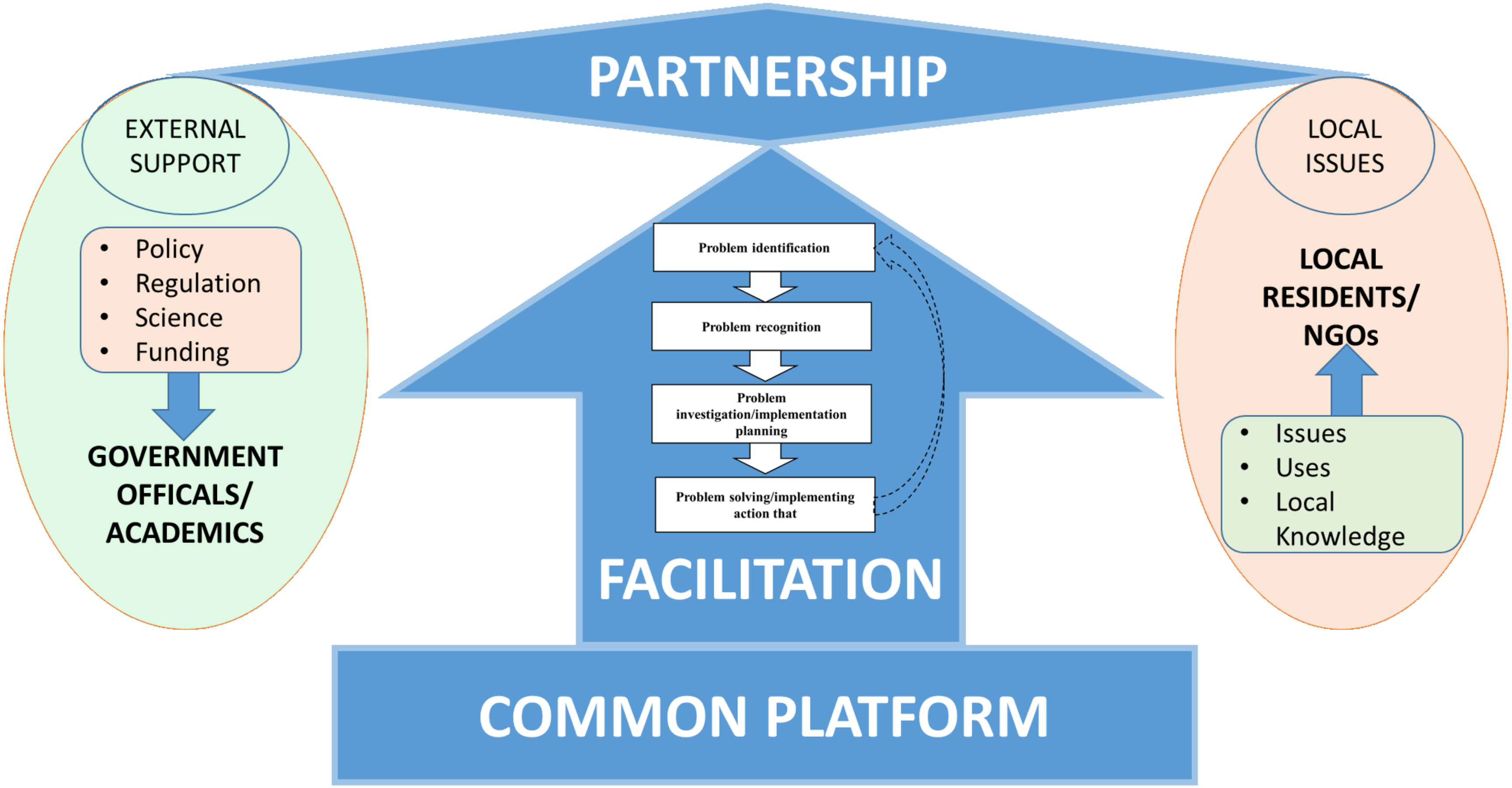

Figure 3-9. Concept of the New Management Framework as a pendulum balance, with base (common platform), beam (partnership among major stakeholder group) and pillar (facilitation), to perform the *balancing act* of bringing *external support* to address *local issue* towards sustainable watershed management.

3.2 SUFFICENCY OF NECESSARY CONDITIONS

The analysis of all eight cases reported in previous sections revealed that none had demonstrated neither integrated actions among government agencies nor an interdisciplinary approach. These two features were identified as requirements for sustainable watershed management to address complex and inter-related water resource issues associated with urbanization. A likely explanation is that the cases reviewed were focused on addressing a single issue such as agricultural runoff (Saxony, Germany & Ohio, USA), algael blooms (WW, Australia), water supply and sanitation (Punjab, Pakistan), groundwater irrigation (Punjab, India), and industrial pollution (Tapalk, Indonesia). While the Neuse, USA and Mae Sa, Thailand cases addressed multiple issues associated with agricultural runoff and urban runoff, neither one reported success in addressing the urbanization and land use change related issues because they lacked an inter-agency coordination and interdisciplinary approach. Similarly, all four bottom-up cases reported that none of them had the mechanism to sustain the process of planning and implementing going forward. It is unclear at this stage how the three elements of new management framework are equipped to address an interdisciplinary approach in a self-sustaining set up. Therefore, further literature reviews were conducted to identify additional conditions to fill needed element gaps for an interdisciplinary approach and self-sustaining model and were integrated into the framework.

3.2.1 Interdisciplinary Approach

It is important to make sure that the formulated management framework has features to sufficiently accommodate the interdisciplinary decision-making approach at the watershed level. If needed, necessary amendments should be made to accommodate the necessary conditions in the framework. As previously reported in Chapter 2, there are three necessary conditions identified to develop and maintain an interdisciplinary approach.

1. Establishment of a strong knowledge base – to help design and implement informed water management policies and strategies.

2. Integrated action across all water management issues – no singular solutions by a single discipline are sought without full stakeholder participation, with whom all impacts and improvements across the spectrum of water management are evaluated.

3. Promotion of strong community awareness and participatory process – to enhance stakeholder involvement in the management decision-making and implementation process.

The intention of the common platform is to provide the base for providing the needed knowledge from both local and expert partners for watershed management. The partnership provides the key players and the facilitation provides the needed function to appropriately design and implement informed water management policies and strategies. Similarly, partnership from all involved disciplines, and facilitation, through the same regular meetings, and addressing all issues makes sure that the impacts and improvements are evaluated across all applicable disciplines. The main focus of the new framework is appropriately integrating the top-down and bottom-up approaches by eliminating the limitations (weaknesses) of both approaches and incorporating needed elements to fill identified gaps. One of the major limitations of top-down approaches was the absence of local collaboration and local stakeholder engagement. Also, one of the major criticisms of bottom-up approach was tokenistic (symbolic) participation of stakeholders.

As such, the three elements of the new management framework were formulated to make sure that all parties are appropriately identified, invited, included, and involved in deliberation of issues towards effective decision making. Furthermore, the systematic steps of addressing a watershed issues through constructive deliberation by the way of regular meetings with multidisciplinary stakeholders is a critically important feature to make sure that each issue gets enough interdisciplinary attention. Table 3-5 summarizes how the three elements of the new management framework provides the sufficiency for the necessary conditions identified for an interdisciplinary approach in accommodating them.

Table 3-5. Overview on the three elements of the new management framework in meeting the necessary conditions identified for interdisciplinary approach.

New Management Framework	**Conditions for Interdisciplinary Approach *(Hooper 2003)***		
	Strong Knowledge Base	Integrated action across all issues	Promotion of community participation
COMMON PLATFORM	√		√
PARTNERSHIP	√	√	√
FACILITATION	√	√	√

3.2.2 Self-Sustaining Institutional Model

Additional importance is that the new framework has sufficient features to provide self-sufficient institutional structure for interdisciplinary decision making. Chapter 2 also reported four major considerations that are required for self-sustaining institutional model as summarized below.

1. Creation of a stable framework that overcomes fragmentation and overlap of responsibilities.

2. Use of institutional arrangements such as cost-sharing programs, tradable discharge permits, local government planning powers, voluntary actions, regulatory practices, etc.

3. Organizational structures such as democratic and accountable systems, and access to top levels of government; and maintenance of effective coordination of civil and professional science, etc.

4. Development of shared visions across all institutional levels, based on careful problem analyses.

One of the major aspects of the common platform is to provide the necessary base to invite and include all stakeholders in a single set up. Similarly, the facilitations provide the forum for all stakeholders to actively participate in addressing all issues regardless of the area of interest. As a result, it provides the opportunity to understand what others are doing and how it is related to their respective area of interest while helping to avoid fragmentation and overlap of responsibilities. When formulating the new framework, it was important that the successful elements (strength) of existing top-down and bottom-up approaches were retained so that there is less effort in formulating the institutional arrangement. Thus, all three elements of the framework are formulated to provide a sufficient institutional arrangement by integrating already existing regulatory and volunteer programs, possibly by different players and agencies, in a holistic and interdisciplinary set up. The framework appropriately provides the structure, process and function of effective management at watershed level through the three elements to satisfy the conditions for providing organizational structure required for self-sustaining model. Last but not least, the success of the framework relies on the appropriate partnership of differently motivated stakeholders, who are facilitated through democratically acceptable decision making toward shared vision of protecting and restoring the watershed. Table 3-6 summarizes how the three elements of the new management framework provides the sufficiency for the necessary conditions identified for a self-sustaining institutional model.

Table 3-6. Overview on the three elements of the new management framework in meeting the necessary conditions identified for a self-sustaining institutional model.

New Management Framework	**Conditions for Self-sustaining Model (*Lovell et al., 2002*)**			
	Stable platform	Use of institutional arrangements	Effective coordination	Shared vision
COMMON PLATFORM	√	√	√	
PARTNERSHIP		√	√	√
FACILITATION	√	√	√	√

The first and foremost objective of this research is to develop a new management framework that can overcome the limitations of both top-down and bottom-up approaches and to provide a self-sustaining institutional structure for interdisciplinary decision making at watershed level. The new framework was first formulated by initially analyzing practical cases from both top-down and bottom-up approaches through baseline analysis on strength and weakness to identify and then integrated strengths as necessary features while and excluding identified weaknesses and major causes of weaknesses. Due to the absence of features needed specifically for an interdisciplinary approach and self-sustaining model, additional elements were identified as strengths through extended literature reviews and were added as part of the framework. Eventually the necessary conditions, identified from literature, are integrated into the framework for interdisciplinary approach and self-sustaining model. Summarized representation of the new management framework formulated in this chapter is presented in Table 3-7.

Table 3-7. Summarized representation of the new management framework with major elements and the necessary conditions for effective watershed management.

MAJOR ELEMENTS	**Common Platform**	Provides the institutional set up to all parties to be invited, convene, deliberate and ensure meaningful involvement in the decision-making.
	Partnership	Provides the necessary balance of differently motivated stakeholders, from government and private/citizen organizations,, to effectively be engaged in decision making
	Facilitation	Provides the necessary facilitation for stakeholders engaged in the exchange of ideas through interdisciplinary thinking at every step and to encourage democratically acceptable decision making towards addressing the issues to protect and restore waterbodies.
NECESSARY CONDITIONS	**Strong knowledge base**	To help design and implement informed water management policies and strategies
	Integrated action across all issues	No singular solutions by a single discipline are sought without involving all stakeholders, with whom all impacts and improvements across the spectrum of water management are evaluated
	Promotion of community participation	To enhance stakeholder involvement in the management decision-making
	Stable framework	To overcomes fragmentation and overlap of responsibilities
	Institutional arrangements	Such as cost-sharing programs, tradable discharge permits, local government planning powers, voluntary actions, regulatory practices.
	Organizational structures	Such as democratic and accountable systems, and access to high levels of government; and maintenance of effective coordination of civil and professional science
	Shared visions	Across all institutional levels, based on careful problem analyses

4.0 FIELD VALIDATION OF NEW MANAGEMENT FRAMEWORK AT SHAWSHEEN WATERSHED

The second objective of this research is to validate the theoretical new management framework in a practical real-world example. The validation process involves analyzing the linkages between of addressing water resource issues due to urbanization through interdisciplinary approaches for improving environmental water quality and to investigate the decision-making process and identify mechanisms needed to sustain the process. To identify a suitable validation case, four watershed management plans developed to address urbanization impact for watersheds in the eastern United States with similar climate and development conditions were selected and reviewed.

A baseline analysis was conducted to compare these cases to the new management framework formulated in the previous chapter and to select an appropriate validation case. The analysis evaluated the cases for the: Inclusion of the necessary major elements and conditions identified in the framework; Decision-making process applied; Environmental quality improvement documentation; and Suitability of the available information for detailed investigation. The case developed for the Shawsheen watershed, Massachusetts, USA and was selected based on this analysis. The Shawsheen case met the validation criteria and was found to have high compatibility with the theoretical framework.

A detailed validation of the new framework's capacity for successfully mitigating adverse urbanization impacts was conducted using the Shawsheen. A concise version of the field validation is recently published in the Journal of Water Resources and Protection (Saravanapavan and Yamaji, 2018b). Urbanization and associated environmental challenges in the watershed are first discussed, followed by implementation of the framework at the watershed level. The decision-making process in the management framework is discussed in greater details, providing practical examples for replications of the framework in the future.

4.1 SHAWSHEEN WATERSHED FOR DETAIL INVESTIGATION

As previously mentioned, in the United States, the Clean Water Act (CWA) of 1972 is the umbrella regulatory statue that drives all federal and state government programs towards protecting surface waters and restoring impaired waters. In 1987, the federal statute was amended to promote community-based efforts to reduce nonpoint source pollution through development and implementation of watershed-based management plans (US EPA 1996, 2002, 2008). The terms "303(d) list" or "list of impaired waters" refers to a state's list of impaired and threatened waters (e.g. stream/river segments, lakes) that need additional pollution controls in order to attain state water quality standard. States are required to submit their list for EPA approval every two years under CWA. Also, the states are required to develop "restoration plans" (Regulatory term is Total Maximum Daily Load (TMDL)) to address the listed impairments. In general, these plans include an analysis of pollutant sources and their linkages to the causes of impairment and estimation of source reductions needed to attain water quality standards for supporting designated uses. While not a regulatory requirement, states were encouraged to include an implementation plan related to achieving the needed reductions.

All four watersheds selected for review and consideration as a validation case, included listed waters on their respective state's 303 (d) list with one or more impairments since 1998. In each case, TMDLs and detailed implementation plans were developed and followed by significant implementation action using different approached to address the impairments. All four cases represent sub-urban development and associated urban issues in the temperate environment of the east coast of the United States. This section provides an informational overview and evaluation of the four cases with the justification for selecting the Shawsheen case for further investigation as a validation of the theoretical framework.

4.1.1 Examples of Watershed Planning to Address Urbanization Issues

1. ***Ipswich River Watershed Planning (Primary Reference: Horsley and Witten, 2003)***

Watershed and Characteristics

The Ipswich River watershed encompasses a 401 square-kilometer area, north of Boston, Massachusetts in Essex and Middlesex counties. The Ipswich River extends approximately 72 kilometers from its westernmost headwaters in the town of Burlington to its mouth at Essex Bay and Plum Island Sound and then flows into Atlantic Ocean. Approximately 20 tributaries feed into the Ipswich River. The Ipswich River and its watershed gradient is relatively small and the river is a relatively slow moving and meandering system. The watershed is home to approximately 160,000 people and roughly 350,000 people depend on the watershed for public drinking water resulted in of out of basin water transfers. As per the land use map of 1999, residential areas make up 28 percent of the watershed and 40 percent of the area is made up of wooded trees (forested). Approximately one-third of the watershed is fully developed. The Ipswich River watershed waters are commonly used for primary and secondary contact recreation (swimming and boating), fishing, wildlife viewing, habitat for aquatic life, industrial cooling, shellfish harvesting, irrigation, agricultural uses, beachfront, and public water supply. There are no wastewater treatment facilities that discharge within the Ipswich River watershed.

Watershed Issues

In 1997, the Ipswich River was named one of the twenty most threatened rivers in North America by American Rivers, a national rivers protection organization, due to the severity of its low flow problems, pollution threats and loss of critical habitats. The Ipswich River was also listed as "impaired" under the Clean Water Act, due to flow alteration, low dissolved oxygen, areas of nutrient enrichment and the presence of pathogens including fecal coliform (MA DEP, 1998). The Ipswich River Basin is a stressed basin under the hydrological criteria adopted by the Water Resources Commission in its 2001 Stressed Basins in Massachusetts report. A stressed basin is defined therein as one in which "the quantity of streamflow has been significantly reduced, or the quality of the streamflow is degraded, or the key habitat factors are impaired." The Ipswich River Basin meets all three of these criteria and is classified as "highly stressed," by the Water Resources Commission.

Conversion of land from rural farmland to suburban and urban as well as other human activities results in direct and indirect impact to the river and its ecosystem. Development that has occurred without regard for protection of water resources is the principal cause of these problems. In the Ipswich River watershed, development patterns and activities have ignored the adage, "protect the headwaters." Facilitated by the construction of interstates 95 and 93 (major highways connecting states), the headwaters communities have been transformed from semi-rural farm communities to densely developed areas as a part of expansion of the Boston Metropolitan area. The trend toward urbanization later was spreading to other communities, where "sprawl" was changing woodlands, fields and former farms to subdivisions and shopping centers. Development has also paved over significant areas in the upper watershed and in other watershed communities causing in loss of groundwater recharge, which affects baseflows in Ipswich River, as well as aquifer reservoir volumes relied upon for public water supply. Increased residential, commercial and industrial demand for water accompanies development and has resulted in stressing the surface and ground water resources of Ipswich watershed. Development further resulted in expansion of sanitary sewer systems, which in turn further exacerbated another of the Ipswich's water resource problems related to the out of basin transfer of water in the form of both water for public use and as sewage for treatment in out of basin WWTFs. In other words, substantial amounts of water withdrawn from the Ipswich, both through surface water and groundwater sources, is eventually is discharged into other watersheds.

Watershed Planning and Management

The Ipswich River Watershed Association (IRWA) has been in active since 1977 as a river watching environmental advocate and as a group supporting and organizing recreational activities. From early 1990s, MA DEP, as a part of watershed assessment, has conducted several basin wide water quality monitoring activities. Until 1995 and 1996, no organized watershed management or planning existed in the watershed. The Ipswich River Task Force (IRTF) was formed in 1996 in response to recurring no-flow/low flow events, including a severe episode in 1995, which resulted in the upper half of the Ipswich River going dry, with large fish kills and other environmental damage.

This environmental event sparked interests to investigate the causes of the river drying up and assess strategies to protect river flows and develop a regional approach to managing this resource. With state backing, the task force met every other month. IRTF created working groups that focused on science and data, education and water conservation, and committees for steering and master planning. Identifying the origin of the low flow problem, which had been a highly contentious issue and a source of disagreement among stakeholders, was a high priority need. Eventually, IRTF evolved into the Ipswich River Watershed Management Council, an inclusive "stakeholder" organization which has met regularly to pursue studies of the Ipswich River and to evaluate and prioritize solutions.

One of the Council's landmark projects was conducted by the United States Geological Survey (USGS) to develop a comprehensive hydrological model of the watershed; a study of the relationship of aquatic habitat and streamflow; an evaluation of potential management alternatives; and modeling of the "firm yield" of communities that divert surface water from the Ipswich River for reservoir storage. Funding to develop the task force has come from the Massachusetts Environmental Trust. A capacity building grant from the state funded some task force work over two years. Results of the studies on low flow were used to develop a watershed plan that was largely funded through EOEA's grant program, Communities Connected by Water.

Ipswich is one of the exceptions to Massachusetts Watershed Initiative (MWI) program in which the task force undertook the functions of watershed community council, as being the forums for all stakeholders to set goals and make decisions. The task force was created independently of MWI, its mandate drawn from community recognition of the need to address a specific watershed issue. The task force has been able to take advantage of the funding opportunities created through MWI to further its development and accomplishments. Ipswich should be considered as true bottom-up approach by the stakeholders that were motivated by the issues that took advantage of available government program opportunities. In 1998, Ipswich Watershed Team (IWT) was started in parallel, under the state's initiative program, however, it was the constituent of the task force with a state appointed team-leader and IRWA assumed the co-leadership.

Ipswich had the three major elements of the new management framework, common platform – IRTF (also IWT) for all parties to be invited, convene, deliberate and ensure meaningful involvement in the decision-making. The partnership was formed by IRWA, initiated by a non-governmental organization, by inviting all stakeholders, governmental and non-governmental, to address the issue in 1995 and then formed IRTF. Meetings occurred every other month and through a continuous planning and decision making process developed the Ipswich Watershed Action Plan. The Plan was the result of the synthesis of scientific findings, and incorporated the input from many IRTF meetings, individual meetings with stakeholders to identify preferred courses of action, and several workshops and conferences to further prioritize restoration actions.

Due to the prime focus of low flow and associated activities, the priority and significance of IWT were less concentrated on other issues. A TMDL was developed for bacteria impairment by state (MA DEP, 2006) with the collaboration of IRTF. However, the TMDL lacks in specifics on implementation plan and action. Due to the limited and no implementation activities associated with controlling non-point source pollution, the 303 (d) list of 2014, have more segments and pollutants, listed compare to the 303 (d) list of 1998. Although a substantial amount of actions on the ground occurred with regard to the low flow issue over 25 years, the success and improvement of water quality is yet to be monitored continuously and reported.

2. ***Penjajawoc Stream Watershed Planning (Primary Reference: BSA Environmental Consulting, 2008 and Tetra Tech, Inc., 2003)***

Watershed Characteristics

The Penjajawoc Stream Watershed is a 23 square kilometer watershed located primarily in the northeast section of Bangor, Maine in Penobscot County. Penjajawoc Stream is an 8.4 km long third order stream. Meadow Brook and the Mt. Hope Cemetery Watershed (Unnamed stream) are the major tributaries. Although most of the watershed falls within the Bangor City limits, portions of the Mt. Hope tributary watershed lie within the town of Veazie to the northeast. The upper watershed contains a large 1.2 square kilometer emergent freshwater marsh known as Penjajawoc Marsh, which is bisected by the now discontinued Veazie Railroad bed. The stream originates at an elevation of 6.1 m above sea level and flows southeasterly to an elevation of 0.6 m where it joins the Penobscot River, which flows into the Gulf of Maine. The highest gradient within the watershed is approximately 3.0% but the overall average gradient is closer to 1.0%. The headwaters and upper portion of the watershed are composed of forestlands, cultivated lands, wetlands, and low-density residential development. The middle portion below the marsh is composed of high-density development consisting of a large retail mall and numerous smaller commercial centers. The lower portion is primarily older, low-density residential development and a cemetery.

Watershed Issues

The Penjajawoc Stream watershed is highly developed, with an impermeable surface area as high as 33% in the middle watershed. As such, the urban stream has been dramatically impacted by stormwater run-off, removal of riparian vegetation, and channel alteration among other concerns. Penjajawoc stream (aka Meadow brook) was listed on the Maine 1998 303(d) list as impaired for dissolved oxygen and degradation to habitat and aquatic life due to non-point sources. A Stressor Identification Analysis was conducted in June 2004 (ME DEP, 2005) and indicated that water quality impairments in an urban stream such as the Penjajawoc is complex and likely caused by multiple stressors. The analysis suggested that aquatic life impairments were likely due to urban nonpoint source pollution and habitat degradation. Watershed development and increased impervious surface cover has resulted in increases in stormwater volumes and rates that have altered stream stability and caused in-stream habitat degradation due to increased bank erosion, siltation, scouring, over-widening of stream channels, and washout of biota. Impervious surfaces also prevented seepage of rainfall to local groundwater, which, in turn, reduced summer stream base flow and habitat availability. Furthermore, increased runoff flowing across developed areas efficiently picks up and delivers more contaminants such as sediment, metals, and toxic substances to surface waters.

Watershed Planning and Management

Watershed management and planning began in late 1990s and early 2000s primarily by the state government agency, Maine Department of Environmental Protection (ME DEP) and the federal agency, US EPA, through conventional top-down approach. Initially, efforts focused on developing a water quality and hydrological model (Tetra Tech, 2003) and the state's water quality monitoring and reporting through its watershed assessment program. Later ME DEP conducted a bio assessment and stress analysis (MEDEP, 2005) to further support developing a TMDL for Penjajawoc Watershed (MEDEP, 2007).

Prior to the TMDL development process, which in accordance with the CWA requires a general public notice and feedback process, there wasn't any reported public engagement or participation appears to be existed. The final TMDL reports (ME DEP, 2007) that public participation for the Penjajawoc Stream TMDL development process was ensured through several review avenues by key stakeholders including the City of Bangor, Penobscot County Soil and Water Conservation District, University of Maine, George Mitchell Center, Maine Audubon–Penobscot Valley Chapter, the Penjajawoc Stream Watershed Work Group, and Bangor Area Citizens Organized for Responsible Development (BACORD). While the State developed TMDL successfully satisfied the federal TMDL regulatory requirements (e.g. source identification etc.), it did not include a detailed implementation plan.

Due to the regulatory implications that the final TMDL has on their National Pollution Discharge Elimination System (NPDES) permit for their municipal stormwater system, the City of Bangor initiated the development of a detailed watershed management plan (BSA Environmental Consulting, 2008) designed for achieving the established reductions of the TMDL analysis. The plan was developed by the City of Bangor with participation from ME DEP, the Penjajawoc Stakeholder Working Group, and BSA Environmental Consulting. The Penjajawoc Stakeholder Working Group was comprised of municipal, state, residential, commercial, and conservation representatives. This Stakeholder working group met several times during the process (Fall 2007 to Spring 2008) to provide input, develop recommendations, and review the plan. Although a partnership was formed, it was temporary and task oriented. Thereafter the involvement of Stakeholder Working Group was limited.

Penjajawoc is a typical example of top-down flow of responsibility of a program that leads to local actions on the ground. In early 2000, the federal government provided support to ME DEP through TMDL development program funding. Following development of TMDL, the state government began to work with the City of Bangor concerning TMDL-related requirements for their NPDES stormwater management permit. Consequently, the city developed a watershed management plan with local stakeholder participation. As per the watershed management plan, the City intended to impose a stormwater fee to fund the implementation of the plan's recommendation. However, the city's efforts to establish fees failed because of local opposition and, as a result, recommended implementation activities have stalled.

In this case, the process for public participation was driven by a top down regulatory process that clearly lacked the forum for adequate information sharing and engagement with the local private citizenry, nor did it adequately raise awareness of issues to justify their support of the necessary fee program to pay for implementation. Also, the process missed the opportunity to identify issues important to the local public that could also be addressed as part of developing the TMDL and watershed management plan. A recent report (ME DEP, 2016) mentioned that there were still negotiations occurring between the City of Bangor and ME DEP about revisiting needed restoration activities through either the TMDL process or an alternative restoration plan that would result in more immediate action on implementing needed restoration activities. One can easily attribute the delays and uncertain situation of implementation actions to the failure of the state and federal government involving the stakeholders in the process of planning from the beginning. As a result, there was no improvement in the recent 303 (d) list in 2014 compared to the 1998 303 (d) list.

3. *Piscataway Creek Watershed Planning (Primary References: MDE 2006 and Tetra Tech, Inc., 2015)*

Watershed Characteristics

The Piscataway Creek is 29.3 kilometers long, beginning at Joint Base Andrews (JBA) (Popularly known as Andrews Air Force Base) and ending at the Potomac River below Washington, D.C. across from Mt. Vernon. The watershed is 175 square kilometers. Historically a predominately forested watershed, agriculture dominated the landscape through the late 1800s, after which time urbanization began to replace agricultural land uses. The urban area in the watershed is largely residential land (31 percent of the watershed), with the majority being medium-density residential (42 percent of urban land). There are also significant areas of forested land (43 percent); institutional land (such as schools, government buildings, and churches) (8 percent); and commercial/industrial land (2 percent). The large area of institutional land in the northern part of the County is JBA. The population of the Piscataway Creek watershed is more than 121,230 persons as per the U.S. Census 2010.

Watershed Issues

The installation of Andrews Air Force Base in 1942 was the initial striking change to the watershed. Followed by the installation, the business and industries and associated residential developments moved into the watershed. In addition, sub-urban development around Washington, D.C., and the metro train expansion to the Prince George's County also made the watershed a bedroom community to Washington, D.C. The overall percent imperviousness is about 13, however it is as high as 40 percent at JBA. The Piscataway Creek Non-Tidal Watershed (02-14-02-03) was first identified on Maryland's 1996 section 303(d) list as impaired by nutrients and sediments, with fecal bacteria added to the 2002 section 303(d) list and biological communities added to the 2004 section 303(d) list followed by continued assessments of the state government, Maryland Department of Environment (MDE) and the Prince George's County (PGC) county government. Benthic Index of Biotic Integrity (B-IBI) sampling in the Piscataway Creek watershed showed that approximately 60 percent of sites are rated as biologically degraded, having B-IBI ratings of Poor to Very Poor. Sources of pollutants in the watershed are varied and include point sources as well as nonpoint sources. Point sources were permitted through the National Pollutant Discharge Elimination System (NPDES) program and do include stormwater discharges from municipal owned systems. In the Piscataway Creek watershed, all sources of pollutant loading not regulated by NPDES permits were considered nonpoint sources. Non-point sources identified in the Piscataway Watershed includes pollutants associated with failing septic system, unregulated stormwater runoff, and agricultural runoff.

Watershed Planning and Management

Conventional top-down watershed management and planning began in late 1990s and early 2000s driven primarily by the county government agency, state government agency, Maryland Department of Environment (MDE) and federal agency, US EPA. MDE has been conducting water quality monitoring from early 1990s focused on nutrients, sediment, fecal coliform, dissolved oxygen and biological and chemical oxygen demand. Additionally, the County government completed two rounds of a countywide bio-assessment studies have been completed (first round from 1999 to 2003 and second round from 2010 to 2013). The Piscataway Watershed is part of the Chesapeake Bay Watershed and as such it was included in the federal government's Chesapeake Bay Program with involvement from other national and regional level non-governmental organizations (NGOs). Other than limited coordination, all efforts were narrowly focused towards meeting respective federal, state and county government CWA-related program objectives (e.g., TMDL and NPDES Permit).

MDE developed TMDLs (MDE, 2006) to address impairments caused by the violation of water quality standards for indicator bacteria (Enterococcus). The resulting percent reduction in indicator bacteria loads to Piscataway Creek is 42.6 percent. In addition, US EPA recently developed an overall TMDL for the Chesapeake Bay watershed for nitrogen, phosphorus, and sediment 2010. The percent reduction WLAs for nitrogen, phosphorus, and sediment varies by water body ranging from 10 percent to 26 percent for total nitrogen; 32 percent to 41 percent for total phosphorus; and 29 percent to 31 percent for total suspended solids. The County has developed a Watershed Implementation Plan (WIP) in response to the Chesapeake Bay TMDL (PGC DER 2012). Although the TMDLs identified the reduction target required, they failed to identify how to meet the targets other than with general recommendations and guidelines in the form of tool box, factsheets etc. In 2014 MDE issued Prince George's County a new MS4 permit. The County's new permit required the development of local watershed restoration plans for each approved TMDL by January 2015. The watershed restoration plans must present the County's multi-faceted approach to control pollutant discharges to the storm drain network to address urban pollutant reduction goals established under approved TMDLs. This was the first time that a specific watershed management plan was required in municipal stormwater NPDES permit to meet the numerical targets of TMDL since the first permit was issued in 1993. As a part of the compliance to the NPDES permit mandate, the county developed a restoration plan for the Piscataway Watershed (Tetra Tech, Inc., 2015).

As a part of the public outreach and participation requirement of the NPDES permit, the county has been implementing several stakeholder involvement programs (PGC DE, 2017). However, there is no formal stakeholder group or set up to address the issues in the Piscataway Watershed. As a part of TMDL reporting and public commenting requirement, the stakeholder involvements took place. As part of the public outreach and involvement in the restoration planning, the County has held public meetings on the restoration process. Two public meetings were held in July 2014 to introduce the restoration planning process and to seek public feedback and suggestions. In addition, the County held a public hearing in November 2015 to present the restoration plans to the public and to receive public comments. It was important to note that there was no involvement of stakeholders in the planning or decision-making processes.

Piscataway is another, similar to Penjajawoc Watershed, typical example of top-down flow of responsibility of a program that leads to local actions on the ground. The federal and state governments initiated after developing TMDL, the state government flows the responsibility to municipal government through NPDES permit. As per the County's WIP, the county began imposing a stormwater fee as a part of the property tax to fund the implementation actions.

According to the annual reporting of the county (PGC DE, 2017) about 14 percent of identified recommendations were implemented by 2017. Although there are little or no interdisciplinary or inter-departmental coordination among each level of the governments, there is a good collaboration in different levels of government that was motivated by TMDL and NPDES programs. Unfortunately the agencies, federal, state, and county agencies addressing failing septic system (Public Health Departments) and agricultural runoff or the agencies addressing habitat and aquatic life were not involved in the planning. There were no single or multiple issues that motivated the private citizen seeking a partnership or facilitation towards watershed planning other than the invitations from the government agencies. Although there are local environmental and land conservation groups that were located in the watershed, such as Accokeek Foundation, they were not engaged in planning and decision making process. Despite a smooth development and implementation of watershed plans, the success is yet to be reported. As a result, there was no improvement in the recent 303 (d) list in 2014 compared to the 1996, 2002, and 2004 303 (d) lists that first reported the impairments.

4. Shawsheen River Watershed Planning (Primary References: MA EOEA, 2003a)

Watershed Characteristics

The Shawsheen River Watershed drains an area of about 200 km^2 to the northwest of the Boston metropolitan area in eastern Massachusetts, USA. The Shawsheen Watershed includes approximately 97 kilometers of named streams including major tributaries and main stem. The main stem of the Shawsheen River flows 40 kilometers from the headwaters in Hanscom Field in Bedford to its confluence with the Merrimack River in Lawrence. About 4.5% of the watershed is covered by wetlands or open waters. The mainstream channel depth generally ranges between one-half and five feet. It is impounded by small impoundments at Ballardvale Village and at Stevens Street, both in Andover. Elsewhere, the relatively narrow channel, comprised primarily of coarse sand and gravel substrates, meanders generally on a northeasterly course through broad floodplains and extensive freshwater wetlands that provide excellent habitat for beaver, mink, muskrat and several species of waterfowl.

Watershed Issues

Notably, the installation of the Hanscom Air Force Base (HAFB) in 1942 was one of the most striking changes to the nature of this watershed. Significant amount of pervious land (natural land) was converted to impervious land (modified land) as a result of the construction of runways, office buildings, parking lots, roads, residences, etc. The natural channels and streams were replaced by concrete culverts and deepened and widened channels to accommodate the stormwater runoff from increased impervious surface. According to (Saravanapavan et al., 2000), about 66% of the land in the Shawsheen River Watershed was covered by forested land (wooded trees), wetland, natural crop and pasture in 1930s. But it was reduced to about 34% by the year of 1999. This alone explains the conversion of land uses in the watershed. Also, the Shawsheen River was placed on the state of Massachusetts' list of impaired water bodies for pathogens, sediment and siltation, metals, turbidity, nutrients, organic enrichment and low dissolved oxygen, and other habitat alterations (MADEP, 1999).

The urbanization process had caused substantial degradations in the hydrological (Saravanapavan et al., 2000), ecological (Saravanapavan et al., 2014), and biological (Saravanapavan and Tasillo, 2003), conditions in the Shawsheen River Watershed. One of the common stressors, fully or partially contributing, to these impacts is excess stormwater (Saravanapavan et al., 2014).

Watershed Planning and Management

In the early 1970's a watershed organization, the Shawsheen River Watershed Association, was formed by concerned citizens to address fears that contaminants were flowing off the Hanscom Air Force Base property into the mid-basin mainstem part of the river, and threatening the wildlife habitat that resided in the area. When contaminants were contained by the mid-1970's, interest waned and the organization disbanded. Soon after, other citizen interest was resurrected in the mid- to late-1980's to address river pollution. The Shawsheen Watershed Environmental Action Team (SWEAT) was formed out of the need to clean up the river from all the years of neglect. Human borne debris had accumulated on the sides and bottom of the river, from Bedford to Lawrence. Since 1990, this group has removed thousands of tires and hundreds of grocery store shopping carts from the river. Until upon 1995, there was no organized watershed management or planning that existed in the watershed. Initially, the two most active entities in the watershed, the U.S. Air Force at Hanscom (USAF) and the Merrimack River Watershed Council (MRWC) were engaged and soon after began water quality monitoring. With these two partners, a Watershed Team was convened, and began to meet quarterly in mid-1995. In the meantime MA DEP, as a part of watershed assessment, had conducted water quality monitoring activities since 1986 and in 1995, it began comprehensive watershed-wide water quality monitoring. MA DEP joined the team. The results of MA DEP monitoring clearly indicated that bacterial contamination was predominant throughout the basin - 98% of all surface river (including tributaries) waters failed to meet

Massachusetts' water quality standards. Simultaneously, another concern of equal importance came to light - flooding during heavy rainfall periods in 1987 and 1996. Over 100 residences were regularly flooded during large rain events, and half a dozen roads closed to traffic. In addition, a significant drought was observed during the summer of 1999, during which a few segments of the Shawsheen River primarily used for recreational activities almost dried out. It further encouraged SWEAT, who had been not only active in river clean up but also active in recreational uses such as canoeing, kayaking and fishing, to join the team.

In 1998, Shawsheen Watershed Team (SWT) formally began its activities under the state government's Massachusetts Watershed Initiative (MWI) program with a state appointed team leader, although SWT started its function of addressing watershed issues since its formation in 1995. Immediately after its launch under MWI in 1998, SWT developed a formal 5-Year Watershed Action Plan (WAP). WAP, every five years, and an annual plan were the major processes for the watershed team, under MWI organization, to conduct the function of addressing watershed issues. The five goals outlined in the WAP of 1998 were: water quality improvement; understanding flow and flooding; restoring fisheries; appreciating recreation opportunities; and developing a local river advocacy organization. With SWT's support, SWEAT converted to a full-fledged watershed organization called the Shawsheen River Watershed Association (SRWA). This organization began meeting monthly, formed its own charter and constitution, and became a viable nonprofit and non-governmental organization in early 2001. By 2003, it had nearly 100 dues paying members and families. SRWA assumed the co-leadership role of SWT by which SRWA worked together with the state appointed team leader in setting up agendas for quarterly meetings and forming committees and sub-committees. SWT took the advantage of MWI funding to address watershed issues, such as flooding and low flow, bacteria contamination, aquatic life impairment, and enhancing recreational opportunities to encourage private citizen interested in watershed protection.

Shawsheen had the three major elements of the new management framework, common platform – Organization (**Structure** – Team, **Process** – Annual and 5- Year Planning) for all parties to be invited, convene, deliberate and ensure meaningful involvement in the decision-making on the **function** of addressing watershed issues. The partnership was formed by SWT, initiated by a non-governmental organization, by inviting all stakeholders, governmental and non-governmental, to address the issue. Quarterly meetings and continuous planning and decision making have resulted in two action plans, the first one in 1998 and an amended one was in 2003. These plans were the result of the synthesis of scientific findings, and incorporated the input from many SWT meetings, individual meetings with stakeholders to identify preferred courses of action, and several workshops and conferences to further prioritize restoration actions. Another important characteristic that existed in SWT and would not be typically found in the conventional approach was sharing the responsibility. Through comprehensive planning and coordinated actions, SWT demonstrated that the same resources and knowledge could be effectively used when put together and shared rather than isolated and used on an individual basis. An innovative planning approach was born as a solution to a complex and unknown situation in decision making after a long deliberation of all stakeholders as a practical implementation step within the existing regulatory programs to address aquatic life impairment using hydrology as a surrogate. This interdisciplinary approach resulted in addressing flooding, low flow and aquatic life impairments at the same time through the same implementation plan. Almost a decade after developing an implementation plan, the results showed improvement in baseflow, and aquatic life through the actions implemented at USAF (Fuss and O'Neill, 2011). Also, the implementation action throughout the watershed by all involved stakeholders resulted in improvement in bacteria counts (MADEP, 2012). The improvement further turned into removing approximately 8 km of river segments, including a portion of Upper Shawsheen main stem, Content Brook, Meadow Brook, and Fosters Brook in the 2014 303 (d) list compared to 1998 303 (d) list.

4.1.2 Selection for Detailed Investigation

In order to meet the objective of the research, it is important to select the appropriate watershed case for detailed investigation into interdisciplinary approach and decision-making process to improve environmental water quality. Two major criteria for the selection are the existence of the features of the new management framework and improvement in environmental quality.

Ipswich and Shawsheen had common platform to convene, deliberate and ensure meaningful involvement of all stakeholders in the decision-making as IRTF and SWT with the link to MWI program. But Penjajawoc and Piscataway are government driven planning without stakeholder involvement. As such there were no partnership, especially between governmental and non-governmental stakeholders in these cases. However, at Penjajawoc, there was a partnership which was formed after TMDL development, especially to develop a detailed implementation plan. On the other hand, at Ipswich and Shawsheen, a very strong partnership existed at IRTF and SWT respectively. IRWA, with the local membership, lead the partnership with state and federal agencies and brought USGS as experts to provide scientific support at Ipswich. MRWC, SRWA, MADEP, USAF and US EPA formed a strong partnership with appropriate balance between government and non-government stakeholders. At Ipswich, the facilitation was carried out through regular meeting at every other month that resulted in 5 year action plans and associated detailed plans and actions. Shawsheen demonstrated its facilitation through quarterly meetings that resulted in two 5 year action plans and several detailed implementation plans and actions. At Penjajawoc and Piscataway, there were no facilitation mechanisms that existed. In Penjajawoc, the City of Bangor hired a consultant to develop a detailed plan. The consultant facilitated several meetings during the plan development period of less than one year. All three major elements existed in both Ipswich and Shawsheen while Piscataway had none and Penjajawoc only had a limited partnership, nothing else.

All planning efforts considered had either occurred as part of government program or with a support from government, therefore, all four cases exhibited a necessity associated with external support. Those are strong knowledge base, stable framework, institutional arrangements, and organizational structures. The planning at Penjajawoc and Piscataway were from single vision of complying with TMDL and NPDES programs of the CWA, although the assumption is that it will lead to clean water. Therefore, the promotion of community participation was limited to meet the regulatory statues or requirements. In Ipswich and Shawsheen, the planning process initiated from the local issues by primarily non-government stakeholders then linked with government to bring the needed external resources through appropriate programs under CWA. In Ipswich, the groundwater depletion and low flow had reached a level with a high alert. As a result, all the resources were concentrated in only one issue while ignoring others. As a result, there was no integrated action across all issues. However it is important to note that there was an integrated action by all stakeholders on one issue. With the single vision, Penjajwoc and Piscataway had no integrated action beyond the TMDL and NPDES program. At Shawsheen it was demonstrated that there was an integrated action among all issues. The details of the comparison of the three elements and the necessary conditions of the management framework presented in Table 4-1.

Among the cases evaluated, only in Shawsheen the water quality improvement was reported through data and the regulatory action followed in removing the segments from “impaired water” to “clean water.” Although there are reports in implementation actions in all three other cases, the success of the planning efforts are yet to be reported. In Ipswich, the issue is very complicated and require the existing collaborated and committed action to continue for a long time before reporting success. Given that the objectives of this research and the selection criteria of improved water quality through an approach with the features of new management framework, the Shawsheen River Watershed was selected for further investigation in detail.

Table 4-1. Comparison of the features of new management framework in selected cases where watershed plans were developed to address the impacts of urbanization

NEW MANAGEMENT FRAMEWORK	MAJOR ELEMENTS			NECESSARY CONDITIONS						
	Common Platform	**Partnership**	**Facilitation**	**Strong knowledge base**	**Integrated action across all issues**	**Promotion of community participation**	**Stable framework**	**Institutional arrangements**	**Organizational structures**	**Shared visions**
Ipswich Watershed, Massachusetts, USA	**Yes**	**Yes**	**Yes**	**Yes**	**No**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Penjajawoc Watershed, Maine, USA	**No**	**Yes**	**No**	**Yes**	**No**	**No**	**Yes**	**Yes**	**Yes**	**No**
Piscataway Watershed, Maryland, USA	**No**	**No**	**No**	**Yes**	**No**	**No**	**Yes**	**Yes**	**Yes**	**No**
Shawsheen Watershed, Massachusetts, USA	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**

4.2 UBRANIZATION IMPACTS IN SHAWSHEEN WATERSHED

The Shawsheen River Basin drains an area of about 200-km^2 and is located northwest of the Boston metropolitan area in eastern Massachusetts, USA. Shawsheen has thirteen sub-watersheds (Figure 4-1) and it includes all or parts of 12 cities and towns (Figure 4-2).

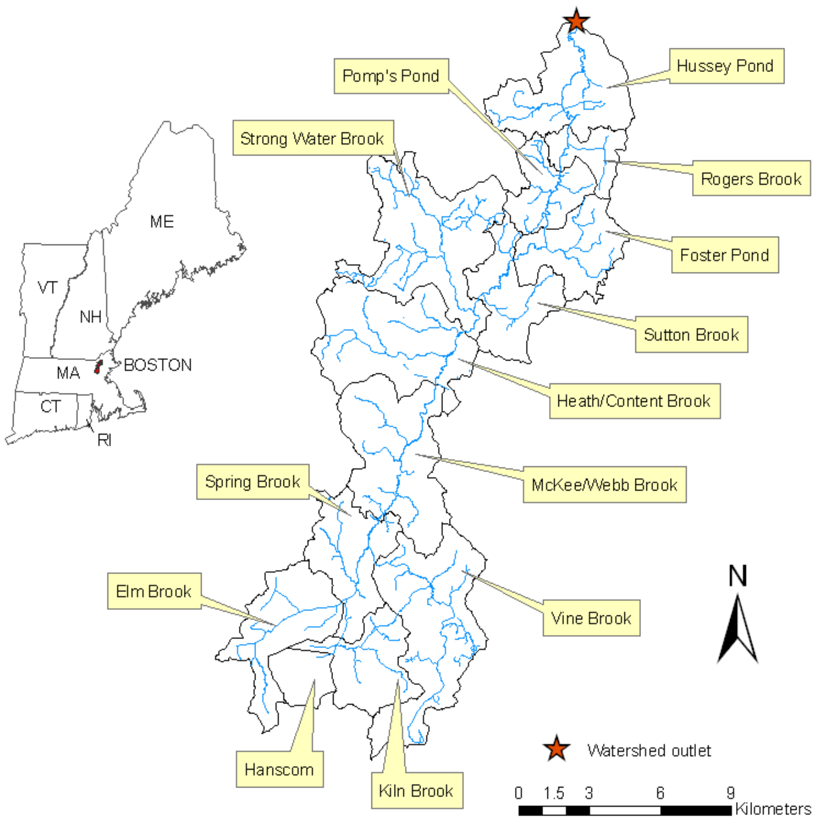

Figure 4-1. The location of the Shawsheen River Watershed in the northeastern United States and its thirteen sub-watersheds (Source: MassGIS 1997).

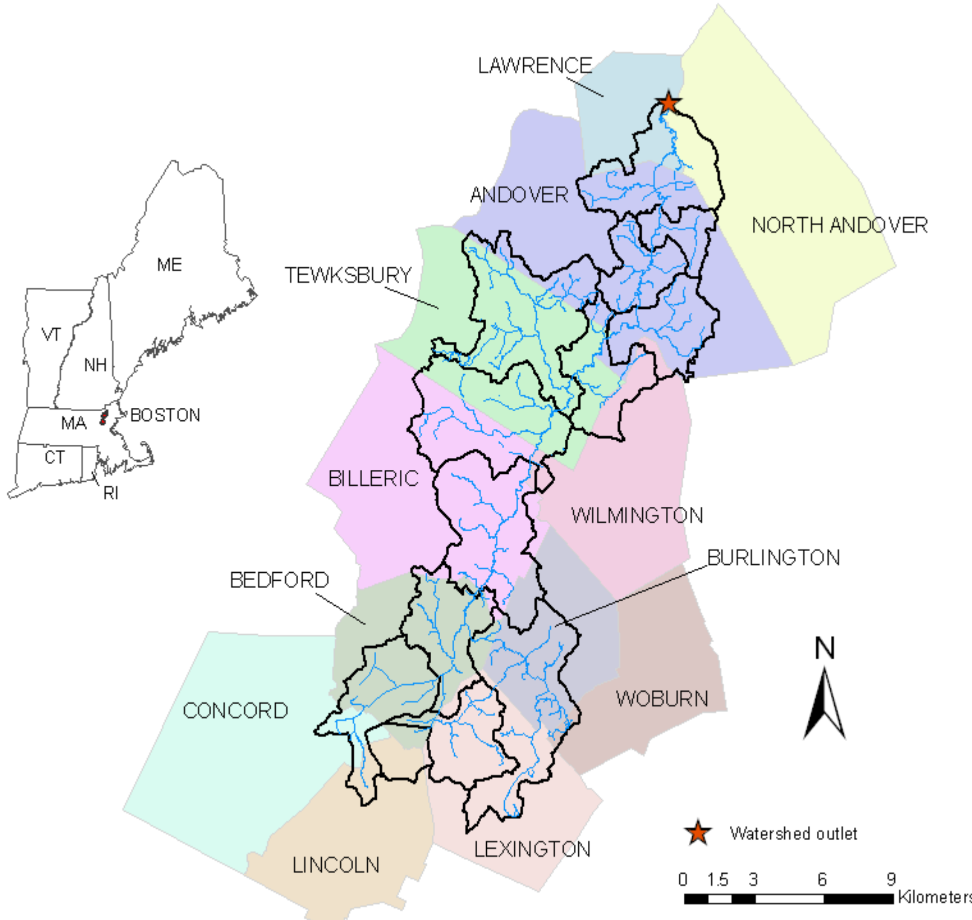

Figure 4-2. The location of the Shawsheen River Watershed and its towns and cities (Source: MassGIS 1997).

The Shawsheen River Basin is rich with history and natural resources, which have changed over time as the watershed has been developed. According to the MassGIS landuse data (MassGIS, 1997), 63% of the total area was used for residential, commercial and industrial and transportation while 37% of the watershed was forested land (wooded trees). Imperviousness of the watershed expressed as percent imperviousness (PI) has been widely used in watershed management as a direct indicator of urbanization. Total impervious area is defined as the sum of areas with roads, parking lots, sidewalks, rooftops, and other impermeable surfaces of the urban landscape. At the time of the Shawsheen case, methods to directly measure impervious cover were not available. Therefore, estimates of PI were made using watershed land use/land cover. Among many ways to estimate PI, employing developed relationship between land use/land cover and PI from published data sets was commonly used in watershed planning studies. For example, MassGIS developed an algorithm to estimate PI from the land use data set that MassGIS developed. The 1997 MassGIS statewide 1:25,000 land use data layer has 37 land use classifications including agriculture, forest (wooded trees), open land, residential (4 classes), commercial, industrial, transportation, etc.

Saravanapavan et al., (2000) employed the relationship between PI and each land use classes (Appendix A) to estimate sub watershed PI. As indicated in Table 4-2, the overall PI of the Shawsheen watershed was estimated to be about 19 % with the Hanscom sub watershed having the highest at 34% and the Pomp's Pond/Baker's Meadow sub watershed having the lowest at 8%

Table 4-2. Landuse and Imperviousness of the Shawsheen watershed and the 13 sub-watersheds (Source: MassGIS, 1997).

Sub-watershed	**Basin Area (km^2)**	**Forest (hectares)**	**Residential (hectares)**	**Commercial/ Industrial (hectares)**	**Transport (hectares)**	**Imperviousness (%)**
Hanscom	5.26	104	86	8	153	34%
Kiln Brook	12.07	271	513	113	101	28%
Elm Brook	15.13	667	440	97	96	13%
Spring/Beaver/Upper Shawsheen	13.80	483	457	186	27	17%
Vine Brook	25.74	670	1078	439	76	25%
McKee/Webb/Jones/Middle Shawsheen	22.95	554	1273	187	4	17%
Heath/Content/Middle Shawsheen	24.19	747	1129	181	59	16%
Strong/Meadow/Middle Shawsheen	26.16	954	758	260	68	13%
Sutton/Middle Shawsheen	12.48	592	314	154	40	17%
Foster's Pond/Lower Shawsheen	12.04	502	441	76	3	10%
Pomp's Pond/Lower Shawsheen	8.96	267	423	27	0	8%
Roger's Brook/Lower Shawsheen	5.54	122	256	85	0	24%
Hussey Pond/Lower Shawsheen	18.10	426	876	165	77	29%
Shawsheen (Entire Watershed)	**202**	**6,360**	**8,042**	**1,979**	**705**	**19%**

Notably, the installation of the Hanscom Air Force Base (HAFB) in 1942 marked one of the most striking single changes to the characteristics of this watershed. Significant amounts of pervious land were converted to impervious land as a result of the construction of runways, office buildings, parking lots, roads, residences, etc. Natural channels and streams were replaced by concrete culverts and channels were deepened and widened channels to accommodate the increased storm water runoff from the new impervious surface features. Development and expansion of the Air Force Base brought satellite businesses and industries to the Shawsheen River Watershed. To support this growth, communities expanded infrastructure, including roads and highways, sanitary and storm sewers, and other public facilities. Laffin et al. (1998) reviewed and compiled the development and population changes in the watershed communities that occurred over a fifty year period (1950-2000). Laffin et al. (1998) also analyzed development trends in this watershed. They defined "developed land" as the land that has been modified by human activities due to urbanization. Developed land generally includes all residential, commercial, industrial, transportation, institutional and governmental land uses. According to Laffin et al. (1998), the percentage of urban land in the watershed reached approximately 25% by 1960 (Figure 4-3). This percentage continued to increase to approximately 50% by 1971. The most striking increase in development occurred between 1951 and 1971 (Figure 4-3).

According to Saravanapavan et al. (2000), about 40 – 60% of the land in the Shawsheen was covered by forested land (wooded trees) in the 1930s. But as development proceeded forest lands were reduced to about 20 – 45% by the 1990s, illustrating the significant conversion of land uses from natural to developed land that occurred in the watershed. Among the thirteen sub-watersheds, Hanscom is the most urbanized watershed with 62% of urban land use that includes Hanscom Air Force Base and Hanscom Airport. In this sub-watershed, forested land had been substantially reduced due to urbanization to account for 20% of the sub-watershed in 1990s. Other urbanized sub-watersheds, namely Kiln Brook, Vine Brook, Roger's Brook, and Hussy Pond, have gone through substantial conversion of forested land to urban land uses as well. These land cover conversions results in increased watershed imperviousness as roads, buildings, and compacted grounds were built on natural vegetated and permeable landscapes.

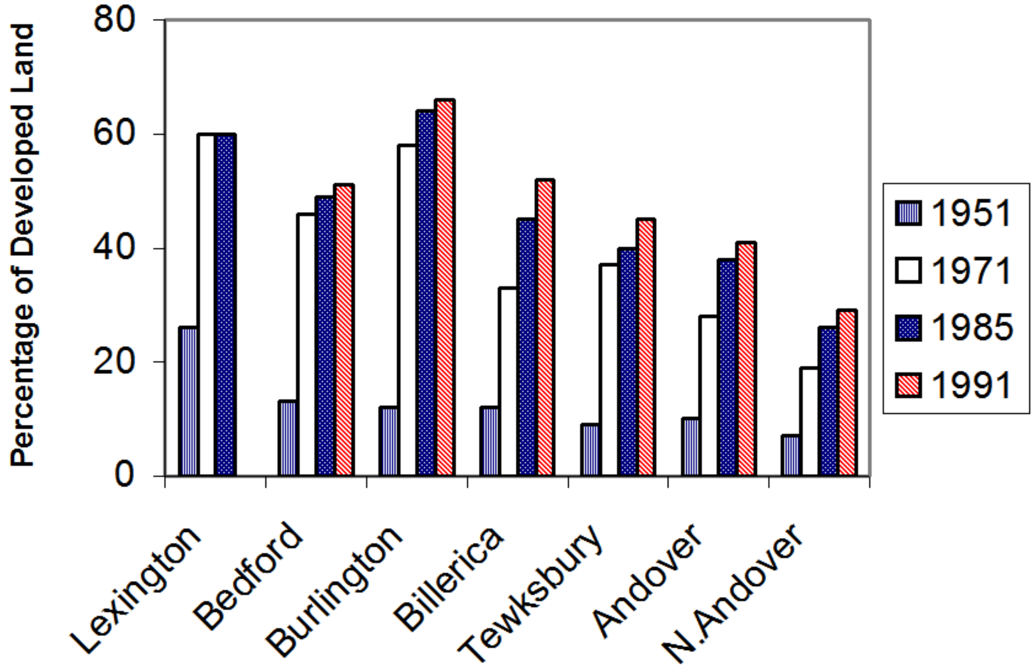

Figure 4-3. Changes in developed land among the Shawsheen communities (Adopted from Laffin et al., 1998).

4.2.1 Hydrological Impacts

As a result of the urbanization, frequent flooding has occurred in the Shawsheen watershed. Also significant drought was observed during the summer of 1999 and the Shawsheen River almost dried up during this period (USGS, 1999). Flooding was generally associated with inadequate capacity of stream to carry excess runoff generated from increased urban land. The municipalities in the watershed had been involved in mitigating the flooding problem using traditional hydraulic solutions, such as widening culverts and bridges, raising the elevations of roads, and widening the channels in 1990s. These investments have had little impact on solving the problem. The flood mitigation measures also failed to focus on the increasing impact of urbanization in reducing stream base flows. The river had become unnavigable by boat or canoe due to low flows during parts of four summers during the decade of 1993-2003 (EOEA, 2003a). The impacts associated with these dry weather cycles and non-existent flow conditions not only effected humans directly, but it also became evident that the damage to flora, fauna, and fish habitats was catastrophic.

Saravanapavan et al. (2000) conducted a study to quantify the changes to water balance due to the urbanization which occurred between 1930s and 1990s. The study focused on identifying sub-watersheds with high impacts to target effective restoration actions. A hydrologic model (Haith et al., 1992) was applied to estimate hydrology, especially the contribution of surface runoff and baseflow to stream flow, for the land uses of 1930s and 1990s (Table 4-3). The ten-year (4/1989 – 3/1999) mean water balance for all sub-watersheds in the Shawsheen was evaluated for pre-development and current conditions. Surface runoff and baseflow contribution show significant variation among the sub-watersheds. Overall, more than half of the precipitation that falls on this watershed accounts for stream flow. However, the distribution of surface runoff and baseflow contributions to stream flow varies substantially based on land uses in the watershed. For example, Elm Brook sub-watershed, a headwater tributary, produces 22.8 cm annual surface runoff and 38.2 cm annual base flow compared to the 50.1 cm and 23.9 cm of Hanscom sub-watershed respectively. Although both Elm Brook and Hanscom have similar topography, soil, and geological set up, the differences in hydrological response are substantial due to the differences in land uses and PI. Increasing imperviousness increases the surface runoff and reduces the base flow because of reduced ground water infiltration.

Table 4-3. Comparison of major land uses in the Shawsheen sub-watersheds for urban conditions in 1990s (Source: MassGIS, 1997) and for pre-urban conditions in1938 land (Source: NRCS, 2000)

Sub-watershed	Basin Area (km^2)	Forest		Residential		Other Urban		Crop/ Pasture		Wetland	
		Urban	Pre-Urban	Urban	Pre-Urban	Urban	Pre-Urban	Urban	Pre-Urban	Urban	Pre-Urban
Hanscom	5.26	20%	38%	16%	10%	62%	0%	1%	44%	0%	8%
Kiln Brook	12.07	23%	37%	44%	43%	31%	1%	0%	8%	2%	11%
Elm Brook	15.13	44%	46%	29%	19%	22%	0%	4%	32%	1%	2%
Spring/Beaver	13.80	36%	61%	34%	28%	28%	3%	1%	1%	2%	7%
Vine Brook	25.74	28%	44%	45%	39%	24%	4%	2%	5%	2%	8%
McKee/Jones	22.95	25%	54%	56%	31%	16%	1%	1%	7%	2%	7%
Heath/Content	24.19	32%	58%	48%	25%	17%	1%	1%	8%	2%	8%
Strong/Meadow	26.16	39%	58%	31%	28%	20%	2%	8%	6%	2%	5%
Sutton Brook	12.48	42%	66%	22%	20%	30%	8%	4%	1%	1%	6%
Foster’s Pond	12.04	43%	53%	37%	34%	16%	7%	2%	0%	2%	7%
Pomp’s Pond	8.96	30%	40%	48%	42%	16%	1%	3%	0%	2%	17%
Roger’s Brook	5.54	23%	42%	47%	43%	29%	6%	0%	3%	1%	6%
Hussey Pond	18.10	24%	44%	50%	44%	23%	2%	3%	0%	0%	11%

The comparison of runoff and base flow contribution to the stream for both urban and pre-urban conditions is presented in Table 4-4. Under the pre-urban land use condition, the surface runoff and base flow contribution was about 30% and 70% respectively in all sub-watersheds. After rapid urbanization, surface runoff increased to more than 60% in a few sub-watersheds, although it ranges from 34% to 67% with an average contribution of 43%. It resulted in an inverse relation to the baseflow contribution. Baseflow was reduced from 70% to 57% on average. It is noticeable that the sub-watersheds with high percent impervious contribute low base flow to the stream. For example, the Hanscom sub-watershed, the highest percent imperviousness of 34%, has the lowest contribution of 33% from base flow. One can notice that the reduction is primarily due to the changes in land use. In general, the forested and agricultural (Crop/Pasture) land uses were converted to urban land uses (Residential, Commercial, and Industrial). The sub-watersheds that are subject to large changes in land uses exhibit large reduction in base flow and increase in surface runoff.

Table 4-4. Comparison of hydrological responses of sub-watersheds in the Shawsheen for urban conditions in 1990s (Source: MassGIS, 1997) and pre-urban conditions in 1938 (Source: NRCS, 2000).

Sub Watershed	Area (km^2)	Runoff (cm)		Base flow (cm)	
		Urban	Pre-Urban	Urban	Pre-Urban
Hanscom	5.26	50.09	20.88	23.86	47.04
Kiln Brook	12.07	27.19	15.31	34.93	44.28
Elm Brook	15.13	22.82	14.15	38.15	45.13
Spring/Beaver	13.80	23.58	14.99	37.58	44.52
Vine Brook	25.74	27.18	19.00	37.19	42.03
McKee/Webb	22.95	24.21	15.66	38.95	45.34
Heath/Content	24.19	22.24	13.61	35.41	42.87
Strong/Meadow	26.16	21.39	14.09	29.80	35.30
Sutton Brook	12.48	22.89	20.80	38.15	39.74
Foster's pond	12.04	18.10	14.94	34.27	36.65
Pomp's pond	8.96	17.09	15.57	30.34	31.46
Roger's Brook	5.54	26.03	15.65	23.57	31.40
Hussey Pond	18.10	25.32	13.64	24.12	32.92

In summary, the results from the study (Saravanapavan et al., 2000) clearly demonstrate that the Shawsheen River Basin was lacking in its baseflow contribution. On the other hand, the reduction in baseflow was compensated by increase in surface runoff during the storm events that causes significant flooding in this watershed. This twofold impact to the natural hydrology in this watershed was primarily due to the extensive development and associated increase in watershed imperviousness.

Water balance analysis revealed the contribution of surface runoff to stream flow doubled in the Hanscom sub-watershed due to extensive developments. A hydrology network model was developed and calibrated at the Hanscom sub-basin (Saravanapavan, 2001). The purpose of this model development was to quantify the stormwater runoff (peak and volume) at the Hanscom sub-watershed, which has caused severe flooding, and to quantify the consequent physical, ecological, chemical, and biological impacts. The model was also employed to evaluate and recommend solutions to control the flooding and water quality problems associated with stormwater runoff. The Hanscom sub-watershed was further divided into 17 sub-catchments (Figure 4-4) based on topography, land use and drainage system and the SWMM Model Version 4.3 (Huber and Dickenson, 1988) which were applied for the entire drainage system, including drainage basins and transport and storage elements, at the Hanscom sub-watershed.

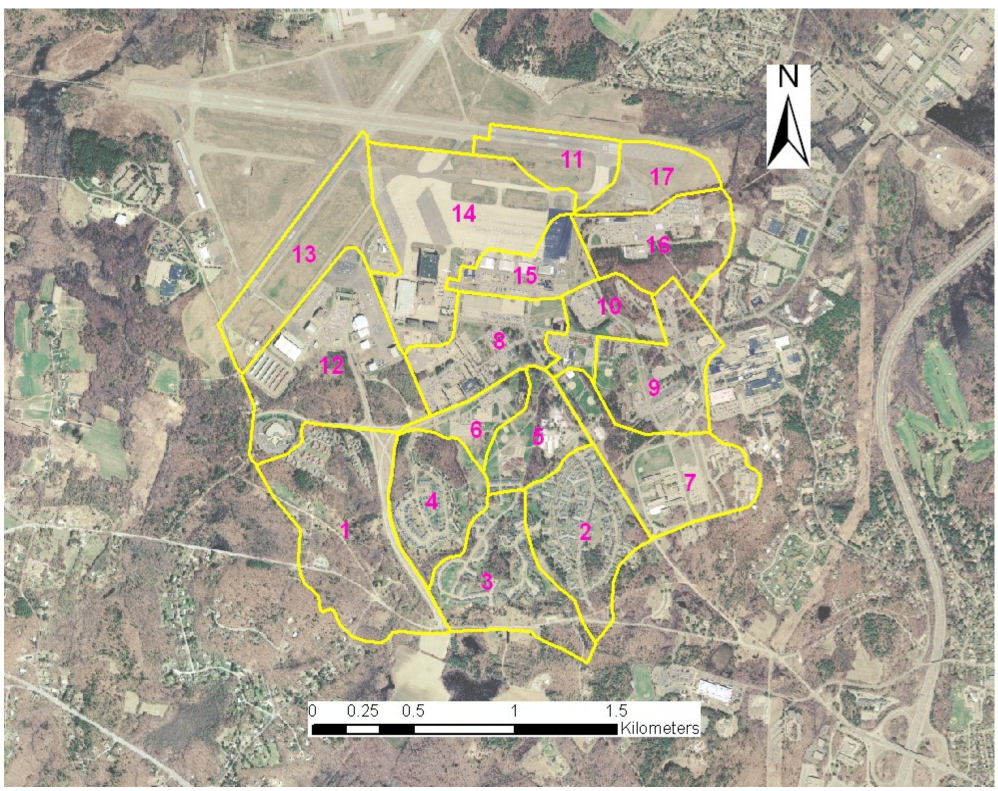

Figure 4-4. Hanscom subwatershed and its drainage basins for flood analysis (Source: USAF, 2000).

Hanscom sub-watershed (Figures 4-4 and 4-5) is the headwater sub-watershed of the Shawsheen River watershed. Native soils within the Hanscom Air Force Base (HAFB) and Hanscom Airport

(HAF) have been drastically modified by construction and earthworks associated with the installation of the HAFB. Because of the generally low degree of relief and glacial effects, there were numerous wetlands and swamps within the base and in surrounding areas. Adjoining sub-watersheds, like Kiln Brook and Elm Brook, still have significant amounts of wetlands and swamps. Much of the original wetlands and swamps in the Hanscom sub-watershed have been filled to accommodate the construction. The Natural Resources Conservation Services (previously known as Soil Conservation Services) has classified most of the soils on the base as "made land." This is the land that has been altered or disturbed by buildings, industrial areas, paved parking lots, and yards. In general, most of the soils at HAFB and HAF, especially in the areas with low degree of relief, fall into Hydrologic Soils Group C, indicating a slow rate of water infiltration when soils are thoroughly wetted. However, the areas with a high degree of relief often fall into Hydrologic Soil Group B and A soils with a fast rate of water infiltration. Major land uses and the percentage of impervious cover of each of the 17 drainage basins in the Hanscom sub-watershed are summarized in Table 4-5. Overall the percentage of impervious cover of the Hanscom sub-watershed is 34.3%. The imperviousness of sub-catchments ranges from 15% to 63%.

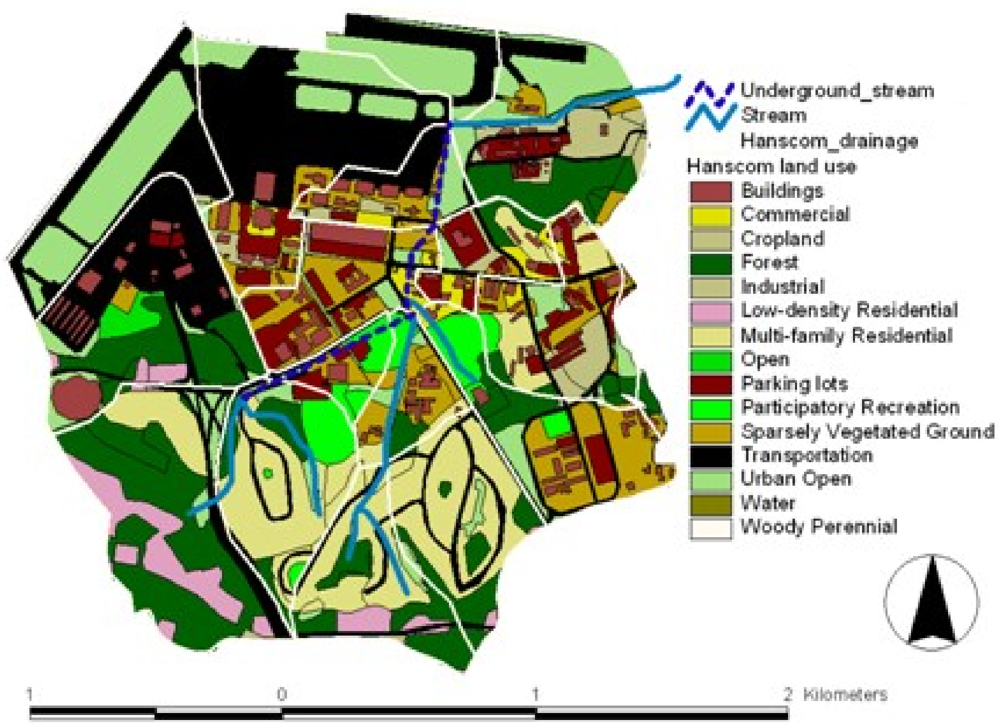

Figure 4-5. Details of land uses, streams, underground streams, and drainage area at Hanscom subwatershed (Source: MasGIS, 1997 and USAF, 2000).

Table 4-5. Major land uses and percentage of imperviousness of Hanscom subwatershed (Source: MasGIS, 1997 and USAF, 2000).

Sub Basin	Total Area (ha)	Land use	Impervious Area (ha)	Percent Impervious
1	56.41	Wooded Trees, Residential, Roads	8.52	15.11%
2	32.44	Residential, Wooded Trees, Open Space	11.32	34.91%
3	28.92	Residential, Wooded Trees, Open Space	7.97	27.55%
4	33.09	Residential, Wooded Trees, Open Space	10.16	30.69%
5	14.87	Institutional, Outdoor Recreational	4.03	27.10%
6	9.01	Institutional, Wooded Trees, Open Space	3.14	34.81%
7	33.41	Institutional, Outdoor Recreational, Open Space	10.71	32.07%
8	27.14	Institutional, Commercial, Industrial, Open Space	12.16	44.81%
9	31.07	Residential, Wooded Trees, Open Space	8.69	27.98%
10	15.02	Industrial, Commercial, Recreational, Open Space	3.09	20.57%
11	17.90	Runway, Airfield Apron, Open Space	7.20	40.23%
12	51.24	General Aviation Area, Industrial, Open Space	19.72	38.48%
13	34.14	Runway, Control Tower Area, Open Space	12.26	35.91%
14	56.48	Industrial, Airfield Apron, Taxiway, Open Space	33.69	59.65%
15	16.17	Industrial, Airfield Apron, Taxiway, Open Space	10.20	63.08%
16	28.49	Industrial, Institutional, Outdoor Recreational, Open Space	5.47	19.20%
17	16.14	Airfield Apron, Open Space, Institutional	3.95	24.47%
Total	**501.93**		**172.28**	**34.32%**

The calibrated and validated SWMM model (Saravanapavan, 2001) was employed to simulate the flow during a 1 year 24 hour design storm (probability of occurrence of this storm is once every year) and a 2 year 24 hour design storm (probability of occurrence of this storm is once every two years) to understand the relative contribution of each drainage area. The design storms were generated using historical rainfall records and commonly used to regulate and design stormwater management facilities in the USA. For Middlesex County in Massachusetts, USA, where Hanscom sub-watershed is located, the one and two year design storms (precipitation in 24 hour) are 63.5 mm and 78.7 mm respectively. The model was applied to compare the runoff generated during the design storms for recent and pre-urban conditions, similar to the considerations of water balance analysis, for each of the 17 drainage areas of the Hanscom sub-watershed. The results are summarized in Table 4-6. The results of each drainage area were used to identify the excess volume of runoff generated and to size the stormwater controls required to address flooding and baseflow issues.

Table 4-6. Summary of SWMM model results for Hanscom sub-watershed from design storm analysis.

Parameter	1 Year 24 hour storm		2 Year 24 hour storm	
	Urban	Pre-urban	Urban	Pre-urban
Total Runoff Volume Per Unit Area (cm)	2.17	0.80	3.26	1.49
Peak flow (m^3/s)	5.95	1.37	7.7	2.7

Overall, detailed flood analysis revealed that the rate of peak flow was increased by 4.3 times and 2.9 times for one and two-year design storms. It also revealed the volume of runoff was increased by 2.7 and 2.2 times during the one and two year design storms respectively. The substantial changes are easy explanations for the severe floods observed in 1996 and 1998 in this watershed (EOEA, 2003a).

4.2.2 Ecological Impacts

Section 303(d) of the Clean Water Act requires state governments in the USA to report to the federal government's Environmental Protection Agency (EPA) a list (i.e., 303(d) list) all impaired water bodies that are not meeting water quality standards and associated goals, despite the application of required technology based control measures. Furthermore, Section 303(d) requires states to develop Total Maximum Daily Loads (TMDLs) for each 303(d) impaired water body, a pollutant allocation plan or equivalent designed to eliminate the impairment and bring the water body into attainment with applicable water quality standards. The Upper Shawsheen River headwaters was listed on the 1998 MA 303(d) list, which was approved by the EPA (MA DEP, 1999). MADEP listed "Other Habitat Alterations" as the impairment for the three-kilometer headwater reach. This reach flows partially through the HAFB and HAF and receives storm water runoff from developed areas including base housing, facilities, and airfields as previously reported.

Monitoring activities and stormwater quality assessment were conducted to evaluate the overall ecological condition of the headwaters of the river by including the three elements of ecological integrity: chemical, physical, and biological. Stormwater quality testing and biological assessments were carried out in the Shawsheen watershed by Rizzo Associates (Rizzo, 1996) and the Merrimack River Watershed Council (MRWC) performed habitat assessments (MRWC, 1998) and macroinvertebrate surveys (MRWC, 1999) in the watershed. Figure 4-6 shows the locations of sampling sites. Monitoring included an extended list of parameters for testing including Total

Suspended Solids, Fecal Coliform, Nutrients, Hydrocarbons, and Metals to provide screening for a wide range of potential contamination. Whole Effluent Toxicity (WET) tests were also carried out at all three stormwater sampling sites (Rizzo, 1996).

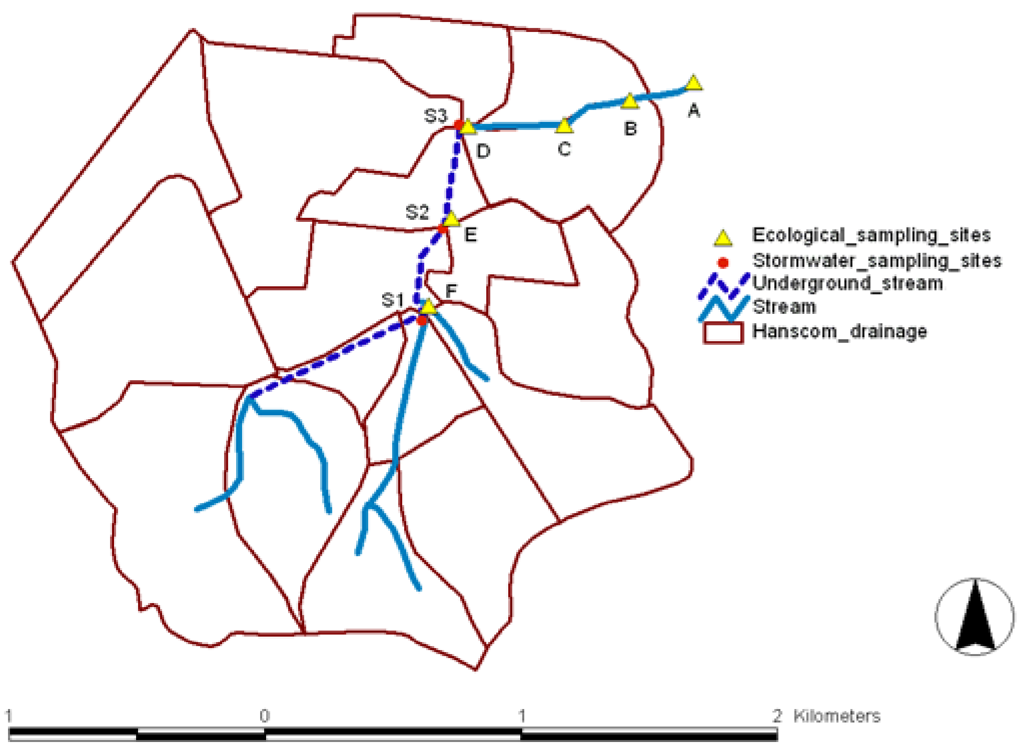

Figure 4-6. Sampling sites at Shawsheen headwaters. At sites 1-3, stormwater quality was tested and at sites A-F macroinvertebrate and habitat survey were conducted (Adopted from Rizzo, 1996).

Stormwater sampling did not detect the presence of volatile organic compounds (VOCs), polynuclear aromatic hydrocarbons (PAHs), or petroleum hydrocarbons. The Whole Effluent Toxicity (WET) tests revealed that the samples were not acutely toxic. However, concentrations of copper at sites 1 and 3, zinc at site 1, and silver at all locations are elevated even with high dilution due to increased stormwater runoff from Hanscom. Elevated levels of metals were believed to partially contribute to the aquatic life impairments in this river segment (Rizzo, 1996). An ecological assessment (Rizzo, 1996) was also conducted in the upper Shawsheen River that involved investigating river substrate and bank materials, aquatic and terrestrial vegetation, water quality, aquatic macroinvertebrate populations, and habitat characteristics. In general, species diversity decreased in the upstream direction (A (fair) > B > C > D > E > F (the poorest)). Excessive sediment deposition was identified at C, D, E, and F. The sediment deposits of fine silts were the highest at site F and likely a contributing cause to reduced species diversity.

Additional monitoring and data analyses (MRWC, 1998, 1999) were conducted to further understand the impairments and potential contributing sources and causes. Aquatic assessments (using methodologies of the River Watch Network's Benthic Macroinvertebrate Monitoring Manual) included four habitat survey sites (UH1-UH4) and one macroinvertebrate survey site (UB1) in 1997. In 1998, macroinvertebrate sampling and habitat surveys were conducted at two additional sites within the headwater segment (SH0.0 & SH0.3) (Figure 4-7).

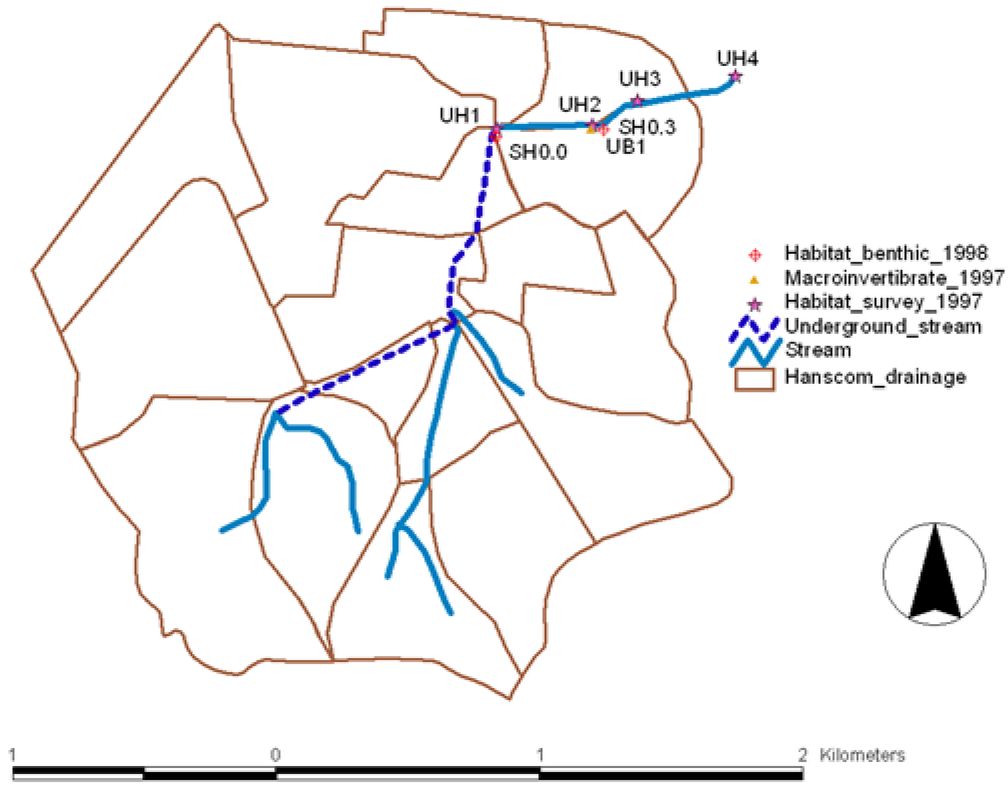

Figure 4-7. Locations of MRWC survey sites. UH1, UH2, UH3, and UH4 are habitat survey sites and UB1 is macroinvertebrate survey site in 1997. SH0.0 and SH0.3 are both habitat and macroinvertebrate sites in 1998 (Source: MRWC, 1998, 1999).

Habitat conditions were "poor" at all sites except at UH4, the downstream most site, which was rated as "fair" condition. Poor habitat conditions were generally associated with characterizations of poor pool substrate, poor pool variability, excessive sediment deposition, lack of channel sinuosity, and poor channel flow status (MRWC, 1997). The 1997 macroinvertebrate survey revealed that site UB1 was seriously impaired due to an abundant presence of pollutant tolerant species (Midges, Crawflies, Scuds, etc.) and lack of presence of pollutant intolerant species (Mayflies, Stoneflies, etc.). In the 1998 survey, both sites (SH0.0 & SH0.3) were found seriously impaired with benthic communities composed of a higher proportion of more pollutant tolerant families that are generally associated with water polluted with organic matter (MRWC, 1998).

These monitoring and assessment efforts (Rizzo, 1996; MRWC, 1997; 1998) all confirmed the existence of significant degradation and the resulting aquatic life impairment in the Shawsheen headwaters. The studies further identified that the impairment was due to multiple stressors associated with pollutants channel morphological instability caused by excessive stormwater runoff volumes and rates, hydromodification, and excessive sediment deposition.

4.2.3 Biological Impacts

The entire Shawsheen River was listed on the 1998 Massachusetts Department of Environmental Protection (MADEP) 303(d) list, which was approved by the Environmental Protection Agency (EPA) (MA DEP, 1999). It was listed for "Pathogen" impairment due to human and urban activities. The Shawsheen River and its tributaries have been monitored for fecal coliform since 1989, with the sampling sites illustrated in Figure 4-8. The database used for the initial analysis contains over 1,200 fecal coliform samples collected by both the Massachusetts Department of Environmental Protection in 1989 (MA DEP, 1990) and in 1995 (MA DEP, 1996) and by the Merrimack River Watershed Council in 1996, 1997 and 1998 (MRWC, 1999). All fecal coliform data were collected between the months of June and October.

The Massachusetts Department of Environmental Protection (MA DEP) conducted two monitoring programs (MA DEP 1990 and 1996) for fecal coliform on the Shawsheen River and its tributaries. Ten stations were sampled in the 1989 study, while samples were collected at 27 stations during the 1995 study. Of the stations in the MA DEP surveys, a total of 8 and 16 were located on the Shawsheen River during the 1989 and 1995 surveys, respectively. The Merrimack River Watershed Council (MRWC) conducted three monitoring programs for fecal coliform on the Shawsheen River and its tributaries (MRWC, 1999). Thirty-six stations were sampled in 1996, seventy-seven were sampled in 1997 and sixty-nine stations were sampled in 1998. Of these stations, a total of 3, 35 and 24 were located on the mainstem of the Shawsheen River in 1996, 1997 and 1998, respectively.

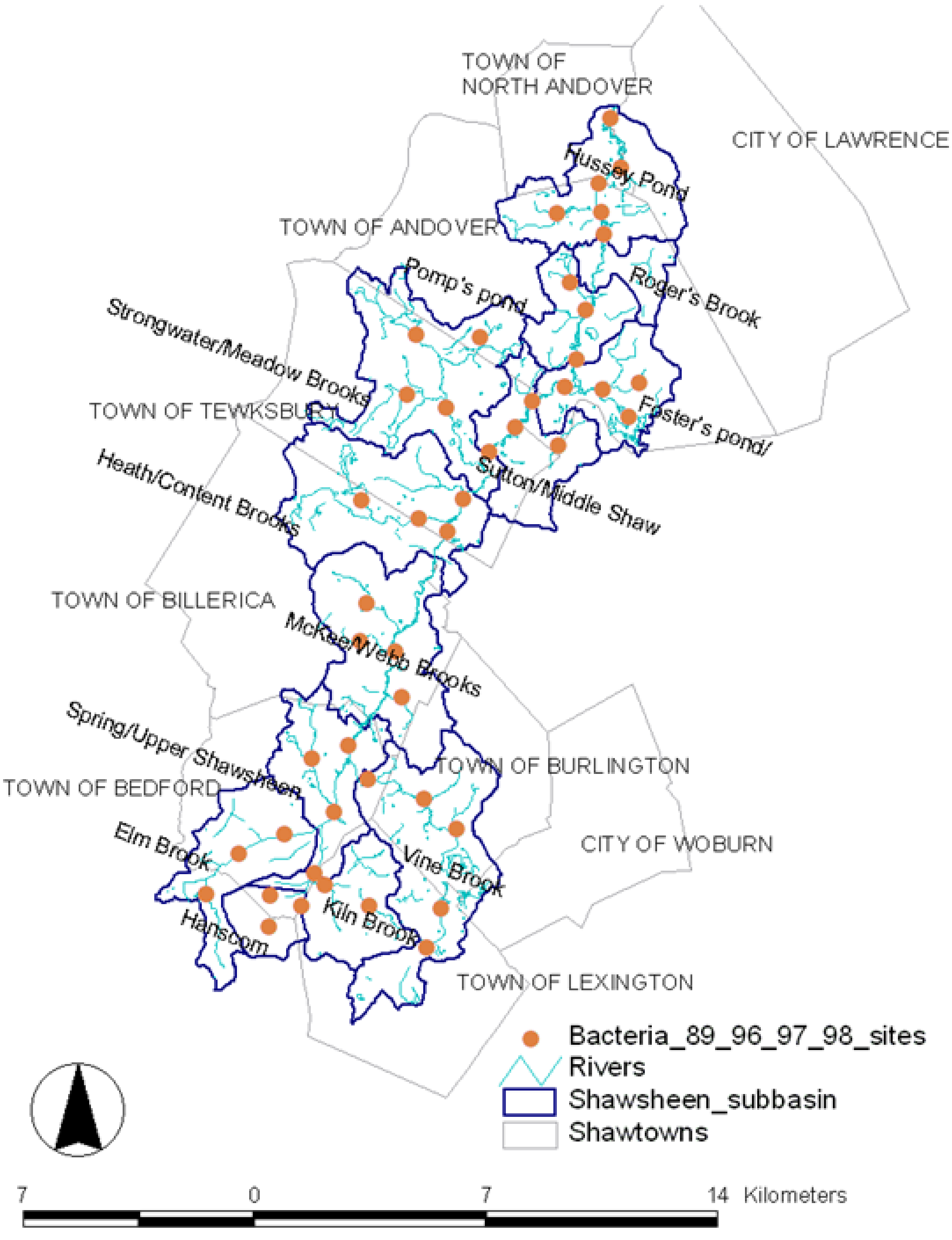

Figure 4-8. Locations where bacteria samples were collected in 1989, 1996, 1997, and 1998 at the Shawsheen River Watershed.

Over 1,200 samples were collected within the Shawsheen River basin between 1989 and 1998. 450 of these samples were collected from the mainstem of the Shawsheen River between 1989 and 1998 at a total of 45 different locations along the length of the river. Review of fecal coliform data clearly revealed the extent of the bacteria violations throughout the Shawsheen River Basin. Violations of the bacteria standard were regularly observed during wet and dry weather events in all four of the waterbodies listed for pathogens on the 303(d) list: Shawsheen River, Elm Brook, Roger's Brook and Vine Brook. These four waterbodies have violated water quality standards during every period in which data were available. Exceedingly high bacteria concentrations (>5,000 #/100ml) were observed in Vine Brook (1995-96, 1997, 1998), Strong Water Brook (1996), Roger's Brook (1996), Content Brook (1996), Elm Brook (1997), North Lexington Brook (1997), several locations along the Shawsheen River (1997, 1998), Kiln Brook (1998) and Pinnacle Brook (1998). In 1997, bacteria concentrations as high as 375,000 #/100ml, 26,000 #/100ml and 25,000 #/100ml were observed in the Shawsheen River, Elm Brook and Vine Brook, respectively. In 1998, bacteria concentrations as high as 112,000 #/100ml and 20,000 #/100ml were observed in Shawsheen River and Pinnacle Brook, respectively. The high concentrations observed in the Shawsheen River were collected from the same station in 1997 and 1998. Forty-five percent of the existing data represent dry weather conditions. These data were valuable for identifying dry weather sources of bacteria such as leaking sewers and illicit sewer connections, but were of limited utility for assessing wet weather impacts. Nineteen percent of the data were collected during wet weather conditions. Wet weather samples were collected by the MRWC in 1996 and 1997. The 1996 and 1997 wet weather geometric means were consistently higher than the dry weather geometric mean. However, violations of the water quality standard were observed during both dry and wet weather.

As reported in MWRC (1999), identified source categories of the bacteria impairment in Shawsheen included: point sources, broken sewer lines, illicit disposal to storm drains, poorly performing septic systems, urban stormwater runoff, and pump station overflows. Data analysis and comparison of data to suspected or known sources identified showed that illicit connections and sewer breaks were the most important sources during dry weather. Urban stormwater was the largest potential wet weather source of bacteria to the Shawsheen River. Other wet weather sources included illicit storm sewer connections and sewer breaks, expected to be a source of bacteria not only during dry weather, but also during wet weather.

In summary, the urbanization process has caused substantial degradations in the hydrological, ecological, and biological situations in the Shawsheen River Watershed. Corresponding with the comprehensive impacts, solutions to mitigating the adverse impacts also require comprehensive measures that cross the several noted disciplines.

4.3 ORGANIZATION OF THE NEW MANAGEMENT FRAMEWORK: MAJOR ELEMENTS

As described in section 4.1.2, the Shawsheen case included the characteristics of the three major elements and the necessary conditions for an interdisciplinary approach and self-sustaining model as identified in the new management framework described in Chapter 3. In this section, the three major elements of the framework found in the Shawsheen case are examined in detail to understand the organizational setup that ensures the function of addressing the issues.

4.3.1 Common Platform

The Massachusetts Watershed Initiative (MWI) was a community based environmental planning and management institutional program and was assessed as one of the most successful initiatives of its kind in the USA (Anderson, 1999; Michaels, 1999 and 2001). The MWI marked a shift from traditional top-down federal and state driven environmental management approaches to a grassroots locally focused management process. MWI coordinated municipal, state, and federal governments, businesses, local residents, watershed associations and other non-profit organizations to improve the effectiveness of their individual efforts to prevent and repair environmental pollution at the local level. Under the MWI program, the Massachusetts state government divided the state into twenty-seven watershed units (27 management units). Each unit had a watershed team that included representatives from local, state, and federal groups, led by a full-time state appointed team leader. A defined structure and process were key elements of the MWI's management methodology. Under the MWI's organizational setup, a structure was created to ensure the process of carrying out watershed management functions with robust stakeholder engagement. Essential features for the MWI's success included:

- Co-leadership roles of the state and non-governmental organizations with strong stakeholder engagement involving citizen groups, business and agricultural entities, community representatives and municipalities in implementing the watershed approach;
- Bottom-up resource assessment, planning and involvement of all interests;

- Watershed focus of problem identification and long-term (5 year) and short-term (annual) plan development;
- Goal of deliberative targeting and allocation of limited funds to watershed priorities, according to where the most environmental protection could be achieved.
- Top-down approvals on priority projects and funding and other resource allocations.

Watershed Teams (WT) formed the structure of the state's watershed protection efforts by providing direct watershed-specific linkages between government agencies, non-governmental organizations, and the grass-root level residents and citizen groups. To further strengthen WTs, new watershed associations and stream teams were formed. Watershed associations are citizen groups (non-governmental), with non-profit status, united toward protecting and restoring the watershed. Watershed associations were considered to be a permanent fixer in the watershed. Stream teams were five to ten people from the business community, municipal government and interested citizens who worked together on a regular basis to assess the issues, identify problems and recommend solutions for the stretch of a stream flowing through their community. Stream teams were considered a temporary fixer and task oriented towards meeting specific objectives of restoration and protection of the watershed.

WT were involved in overall planning and implementation through the development of annual work plans (annual plan) and a five-year watershed action plans (five-year plan). Identifying priority issues and addressing them through the collaborated, committed, and continued (3C) approach were the main functions of WT. Annual plans detailed the environmental issues within the watershed and contained a list of prioritized projects required to address the issues. Figure 4-9 presents the summary of annual planning processes. The priority project list represents a WT's consensus judgment on projects that should receive prioritized funding. Previously, such funding was supplied directly by the MA Executive Office of Environmental Affairs (EOEA) without inputs from local grass-root level participation. WT would submit annual work plan to a "Roundtable" comprised of senior level managers under EOEA, community partners, and a few selected representatives from watershed associations. The Roundtable was the mechanism to ensure that the state agencies would allocate state resources – both people and money – according to the priority issues and actions identified by WT. The Roundtable served as a clearinghouse and priority setting group for the MWI program to review annual work plans, ensure consistency of service, and reconcile competing demands for allocation of resources while supporting the needs of each watershed.

The Shawsheen Watershed Team (SWT) was one of twenty-seven teams that began functioning in 1998 under the MWI, although the team was originally formed in 1995 (EOEA, 2003a). This management unit directed environmental protection efforts for the Shawsheen River watershed, which drains an area approximately 200-km^2, located in the northwest portion of the Boston Metropolitan Area (Saravanapavan et al., 2004). The governing system of the SWT, for the five-year period between 1998 and 2003, is presented below in Figure 4-9. A full-time team leader, appointed by the State, along with the co-leader appointed by stakeholders, were responsible for managing, facilitating, and implementing the objectives of the MWI by leading all activities of the SWT.

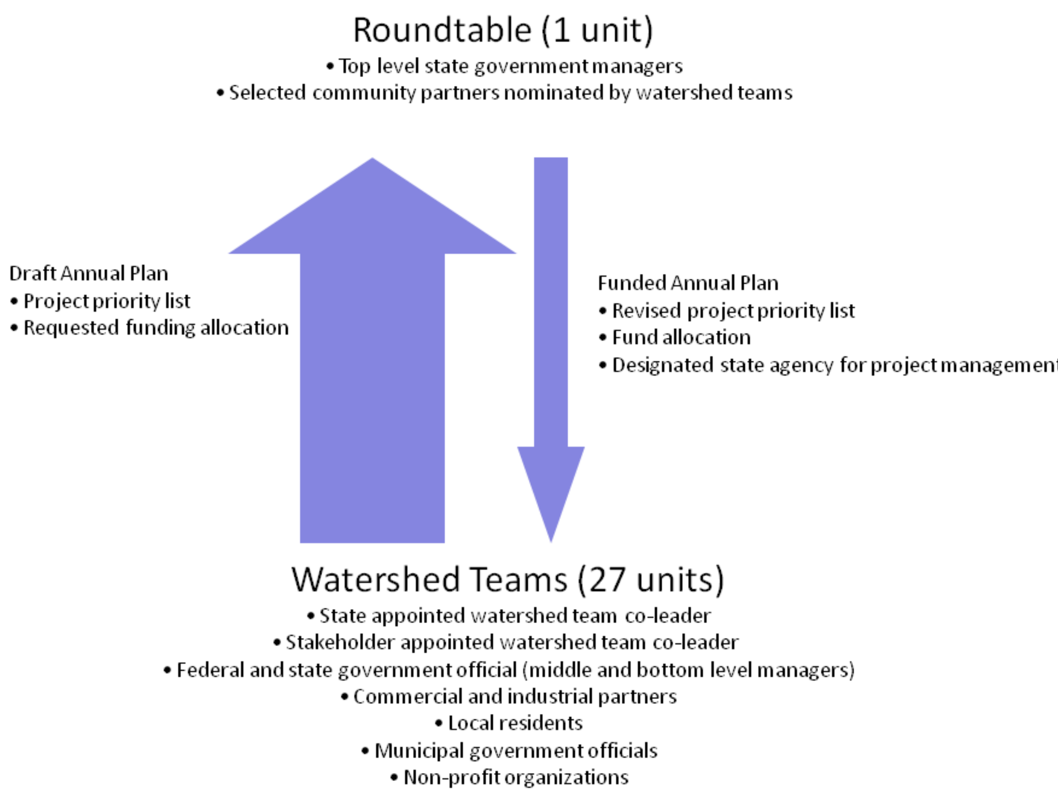

Figure 4-9. Annual planning processes, development, submittal, roundtable review, and approval under MWI.

4.3.2 Partnership

The SWT was composed of members and representatives from the federal, state and municipal government sector, private sector, and non-governmental organizations and private citizens. The SWT includes two major groups of the stakeholders as presented in Figure 4-10. The first group was composed of private residents, non-governmental organizations, the Shawsheen River Watershed Association (SRWA), and the Merrimack River Watershed Council (MRWC) and private business and industries such as Raytheon, Limno Tech, and Environmental Scientific Services. Flooding, drought and/or water quality related issues in the watershed directly and indirectly impacted this group and motivated their participation in the process. The second group was composed of municipal, state, and federal government employees, who were responsible for implementing government policies, or programs, regulations and related regulatory enforcement activities the regulations of respective governments. This group was mainly motivated through job functions and in successfully carrying out program priorities. Although the collective focus of the SWT was on protecting and restoring the Shawsheen watershed, individual motivation for involvement varied among the diverse group of members. Table 4-7 summarizes the sector, group, and motivational factors and interest of the SWT members.

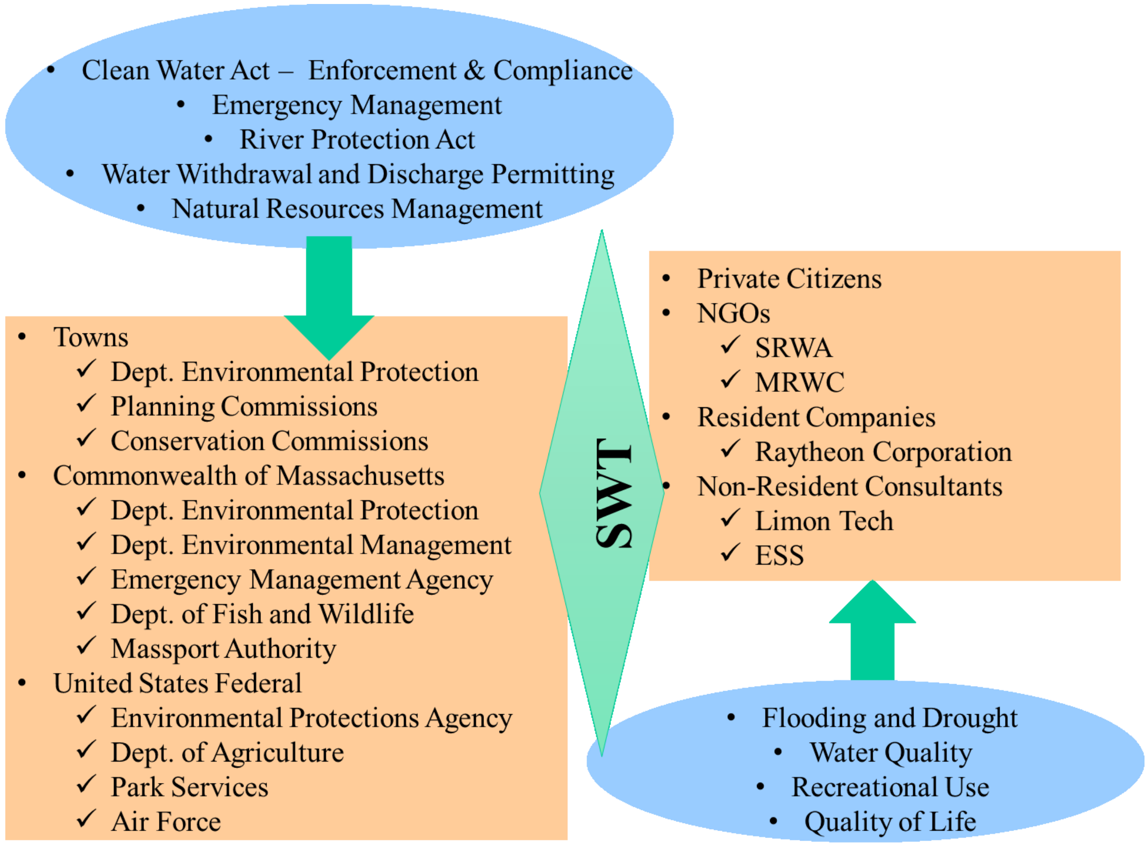

Figure 4-10. Composition of SWT – state and federal agencies, municipal partners, business, industries, regional authorities, NGOs, and private citizens.

Table 4-7. Summary of the members of SWT and the individual interest and motivations.

Sector	Group	Member Name	Motivational Factors and Interest
Public	Federal agencies with regulatory responsibility	US Environmental Protection Agency	▪ Implementing and enforcing environmental programs such as TMDL and NPDES under CWA
	Other federal agencies	US Geological Survey	▪ Scientific studies, research and development
		US Dept. of Agriculture	▪ Agricultural and soil resources protection
		National Park Services	▪ Protection and maintenance of national parks
		US Army Corps of Engineers	▪ Flood control and dam managements
		US Air Force	▪ Required to comply with environmental regulations (role is more like a private entity)
	State agencies with regulatory responsibility	Dept. of Environmental Protection	▪ Implementing and enforcing environmental regulations (Water quality)
		Dept. of Environmental Management	▪ Implementing and enforcing environmental regulations (Water supply) ▪ Flood and flow planning
	Other state agencies	Massachusetts Emergency Management Agency	▪ Flood mitigation
		Dept. of Fish and Wildlife	▪ Fish and aquatic life protection
		Massport Authority	▪ Required to comply with environmental regulations
	Semi-government agencies	Regional Planning Commissions	▪ Sustainable development planning
	Municipal government	Dept. of Public Works	▪ Required to comply with environmental regulations ▪ Flood control and mitigation
		Conservation Commissions	▪ Implementing and enforcing environmental regulations
		Planning Department	▪ Sustainable development planning
Non Governmental Organization (NGO)	NGO & Private Citizens	Shawsheen River Watershed Association ***(Created by SWT)***	▪ Protect Shawsheen River watershed ▪ Promote recreational use
		Merrimack River Watershed Council	▪ Protect the Merrimack River and its tributaries including Shawsheen
		Private Residents	▪ Care and live in Shawsheen watershed ▪ Impacted by flooding

Private	Businesses/ Industry	Raytheon	▪ Located in Shawsheen watershed ▪ Impacted by flooding
		Limno Tech, Inc.	▪ Consulting opportunity
		Environmental Scientific Services, Inc.	▪ Consulting opportunity

The SWT included members from the federal and state government agencies, US Environmental Protection Agency (EPA), MA Department of Environmental Protection (MADEP) and MA Department of Environmental Management (DEM) that were responsible for implementing and enforcing regulations related to watershed protection (sometime these agencies are referred as line agencies). The SWT also included representatives from other government agencies that either had programs related to watershed protection, MA Department of Fish and Wildlife (DFW), Massachusetts Emergency Management Agency (MEMA), US Department of Agriculture (USDA), and National Park Services (NPS), or had resources to assist in watershed protection, US Geological Survey (USGS) and US Army Corps of Engineers (US ACE). Additionally, two other government agencies participated in the team as key stakeholders due to their locations within the watershed and their operations covered by existing federal and state permits, US Air Force (USAF) and Massport Authority.

Local municipal team members typically included public works departments that had responsibility for flood mitigation and compliance with environmental regulations; conservation commissions and planning departments that were responsible for natural resources protection and sustainable development; and local decision makers such as town managers and representatives from mayor's and state legislator's offices.

Regional planning commissions (Merrimack Valley Planning Commission (MVPC), Northern Middlesex Planning Commission (NMPC), and Northern Middlesex Council of Governments (NMCOG)) also participated in the SWT, as they have responsibility for working towards sustainable development in the region. The private non-profit organizations (Shawsheen River Watershed Association (SRWA) and Merrimack River Watershed Council (MRWC)), as well as private residents participated in the team as environmental advocates to restore the health of their watershed. It is important to note that the SRWA was formed by SWT through the MWI process by bringing the individual citizen-participants into a single unit. It is interesting to note that the private consulting companies (for profit companies) were participating in the team process. These private companies saw that this forum is a business development opportunity for them. Regardless of their motivation, these private companies provided substantial scientific support to the SWT.

In summary of group motivations, the issues in the watershed motivated private residents, environmental stewards, watershed groups, non-governmental organizations and local legislators and politicians, because the impacts directly and indirectly effected their communities' quality of life. With respect to the government agency representatives, their motivations were driven primarily by their job functions of carrying out policy, program and regulatory related priorities and responsibilities. It is important to note that the primary goals underlying the government policies, programs and regulatory priorities that federal and state representative were charged with carrying out were to improve watershed health and restore water quality conditions to support CWA goal uses.

4.3.3 Facilitation

The major forum used by the SWT for facilitating the watershed management process was the quarterly meeting. The watershed team leader and the co-leader prepared meeting agendas and facilitated the meetings. Quarterly meetings had generally lasted about 2 hours and the first 30-45 minutes were allocated for team members to report their activities. One quarterly meeting was generally allocated for the development of annual plan. The rest were to review the progress of on-going priority projects and to address the issues brought up by the team members. Occasionally, the SWT invited experts to give presentations on the topics of team's interest. During the five-year period (1998-2003) analyzed for this research, SWT conducted 18 quarterly meetings as summarized in Table 4-7. On average, 20 people attended these meetings in which, on average 13 attendees were government representatives and 7 were from non-government sectors. Overall, the core of the watershed team was formed by 7 people from state government and 4 people from non-governmental organizations who had consistently attended meetings.

Table 4-8. Summary of quarterly meetings conducted in the Shawsheen watershed between January 1999 and March 2003.

Quarterly Meeting		Participants					Major Agenda Items
Year	Day	Federal Gov	State Gov	NGO	Private	Total	
1999	7-Apr	4	10	5	2	21	• Member Updates • Annual Plan • FY 99-00 Priority Projects • Priority Issues – Hotspots
	21-Jul	3	8	8	1	20	• Member Updates • FY 99-00 Finalized Projects and Funding • Priority Issues – Hotspots, Bacteria TMDL and Flooding.
	20-Oct	7	7	4	1	19	• Top Priority Issues • Guest Speaker on Great Medows Wildlife Sanctuary • Ranking Projects
	01-Dec	0	7	5	0	12	• Special Meeting • Member Updates • Targeted Protection Areas
2000	19-Jan	7	13	4	1	25	• Member Updates • TMDL Planning
	4-Apr	2	10	6	0	18	• Member Updates • Annual Plan • FY 01 Priority Projects
	25-Jul	4	12	7	0	23	• Member Updates • Rocco Landfill and Hotspot updates • Priority Project Updates for FY 01
	24-Oct	0	12	5	1	18	• Member Updates • Shawsheen Wetland Restoration Plan • Shawsheen Community Survey on Priority Issues • FY 02 Priority Projects
2001	23-Jan	4	9	4	2	19	• Member Updates • Project Progress Updates
	1-May	3	13	4	1	21	• Member Updates • FY02 Finalized Projects and Funding

							• Shawsheen Wetland Restoration Plan • Mass GIS data
	1-Aug	2	11	4	1	18	• Member Updates • Project Progress Updates
	17-Oct	1	7	4	1	13	• Annual Planning • Priority Projects for FY 03
2002	9-Jan	4	19	2	5	30	• Member Updates • Flooding Updates
	10-Apr	4	8	4	5	21	• Member Updates • Project Progress Updates
	10-Jul	2	6	6	5	19	• Member Updates • FY 03 Finalized Projects and Funding
	10-Oct	3	8	4	1	16	• Member Updates • EPA Initiative Nomination for Shawsheen • FY04 Priority Projects • Five Year Plan 2003-2008
2003	8-Jan	2	10	7	1	20	• Member Updates • Five Year Plan 2003-2008
	26-Mar	3	10	4	1	18	• Member Updates • Five Year Plan 2003-2008 • MWI and SWT Status

If issues were determined to require special attention, sub-committees or steering committees were formed. For example, steering committees were formed in 1997 and 2002 to develop the five-year plans. The SWT developed two five-year plans in the 1998-2003 period. In both cases, steering committees were formed with the responsibility to develop these plans. Final drafts of the plans were presented at quarterly meetings to the full membership of the team to obtain approval.

The MA EOEA allocated $100,000 yearly for priority watershed projects identified by SWT. From 1998 through 2003, the team received a total of $430,000 in project funding to address its priorities (EOEA, 2003a). Also, during this same period, the SWT members secured more than $ 425,000 of additional funding from other sources as matched support and to meet the team's priority project needs. These funding amounts to not account the considerable value of the time and effort voluntarily provided by all team members. In-kind human resources was critical to the success of a variety of project activities including watershed-wide physical, chemical, and biological monitoring, habitat and biological assessments, pollution remediation planning and implementation, GIS data acquisition, Total Maximum Daily Loading (TMDL) development, water balance analysis, flood mitigation planning, riverbank erosion mitigation, river clean ups, and development of a recreation map for the Shawsheen River.

Overall, through the quarterly meeting forums, the SWT successfully facilitated effective watershed management activities and decision making (Figure 4-11) by integrating varied input and perspectives from differently motivated stakeholders through a process of careful consideration, evaluation and deliberation of critical information by the team that led to agreement setting priorities and reaching well-informed decisions.. All these processes were fit into a systematic cycle of steps, problem identification, problem recognition, problem investigation for implementation planning, and problem solving through implementing actions. The quarterly meetings also provided the opportunity for team members with varying backgrounds to bond together while addressing multi-disciplinary and inter-related watershed issues as they continued to work towards sound decision-making in watershed management.

Figure 4-11. Quarterly meeting provided effective facilitation of sustainable watershed management in addressing issue at Shawsheen.

4.4 FUNCTION OF THE NEW MANAGEMENT FRAMEWORK: ADDRESSING URBANIZATION IMPACTS

As discussed in the previous section, the presence of the new framework's organization is confirmed to have existed in the Shawsheen watershed case. This section presents a further exportation of the function of addressing watershed issues in the Shawsheen through an examination of available technical reports, meeting minutes/notes, and the in-person meetings and phone inquiries of selected key SWT. As previously mentioned in section 4.2, the land use changes in the Shawsheen watershed from permeable vegetated cover to the more impermeable cover of developed lands has caused substantial deteriorations in physical, ecological and biological quality of aquatic systems. Therefore, the applications of the functional elements of the new management framework related to the systematic steps for addressing the high priority watershed issues of flooding and low flow, aquatic life and habitat impairments, wide-spread bacterial contamination are discussed in the following subsections.

4.4.1 Flooding and Low Flow

Rapid urbanization and associated impacts resulted in frequent floods in Shawsheen watershed. A significant drought was observed during the summer of 1999 and the Shawsheen River almost dried up during this period (EOEA, 2003a). Flooding was generally associated with inadequate capacity of stream to carry excess runoff generated from increased urban land. The municipalities in the watershed had been involved in mitigating the flooding problem using traditional hydraulic solutions, such as widening culverts and bridges, raising the elevations of roads, and widening the channels in 90s. These investments have had little impact on solving the problem. The flood mitigation measures also failed to focus on the increasing impact of base flow. As a result, it was one of the primary concerns at SWT. In addition, low river flows during dry weather regimes has also sparked citizen concerns. The river has become non-navigable by boat or canoe due to low flows during parts of four summers during the past decade (EOEA, 2003a). Not only the human dimensions of dry to non-existent flows became evident, but also the damage to flora, fauna, and fish habitats was catastrophic during these dry weather cycles. Other than the physical observations and experiences, SWT had no scientific evidences and support to bring the involvement of local decision makers and government agencies together to address the issue. There was a clear conflict of opinion among members on whether the low flow was an issue. More importantly the members from the towns didn't agree on it as an issue. Also there was another conflict of opinion on who contributes what in the flood issue. Realizing the potential ineffectiveness of the isolated efforts of its members and towards resolving the conflicts in opinion, the SWT deemed that a watershed-wide approach was necessary to efficiently address and manage current and future threats to the watershed. The SWT has launched several efforts including a study to understand the impact of urbanization on the hydrological balances and educate the local officials and decision makers to integrate these understanding in practice (EOEA 2003a). In this section, a detailed investigation is reported regarding how SWT addressed the hydrological issues through 3C approach, especially how activities of every step of process (Figure 4-12) of the management framework, such as problem identification, problem recognition, implementation planning and policy adoption, and problem solving and implementing actions, is analyzed.

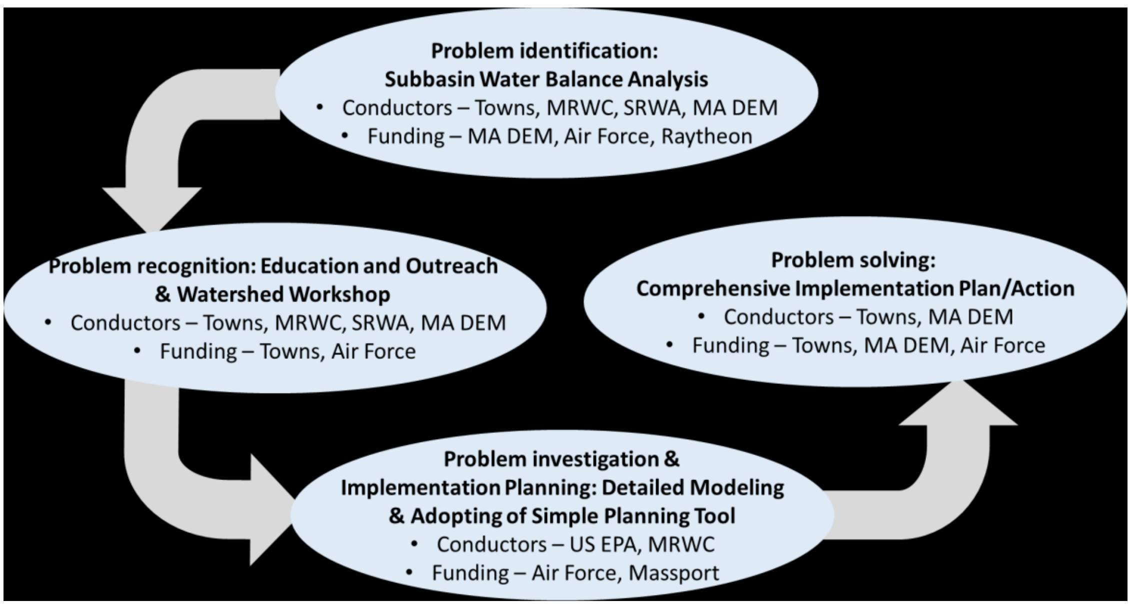

Figure 4-12. Addressing flooding issue through a systematic cycle of steps under the new management framework at Shawsheen.

Problem Identification: Subbasin Water Balance Analysis

Among the SWT members, there were full agreement on the identification of flooding issues, although there were differences in the sources and causes of the problem. However, there were conflicts of opinion on recognition of baseflow issue and the sources and causes. For example, a few members thought that the baseflow issue was insignificant. The downstream municipalities thought that the entire baseflow and flooding issues were associated with the development associated with the Hanscom Air Force Base in the headwaters. In the meantime, the members involved in canoeing and kayaking strongly believed baseflow an issue due to their experience in summer flows. A scientific study was needed not only to understand the impact of urbanization on the hydrological balances and educate the local officials and decision makers, but also to bring the SWT members on a common ground to address the issue. Objectives of the water balance analysis were to: (1) quantify the water balances of urban condition, especially surface runoff and base flow contribution to stream flow in sub-watershed basis; and (2) identify base flow reduction due to the impact of urbanization which occurred between 1930s and 1990s.

Shawsheen watershed has been going through extensive development for approximately five decades. As a result, the natural hydrology has been significantly altered by human activities. The watershed-wide collaborative approach attempts to efficiently invest to mitigate the problems and to avoid future threats to the watershed. Water balance analysis (Saravanapavan et al., 2000) provided the insight into the distribution of surface runoff and baseflow in the stream flow. In the sub-watersheds in the Shawsheen, approximately 35% – 60% of the stream flow was contributed by base flow. However, it was approximately 65% -75% before urbanization. This substantial reduction in base flow, on the other hand, resulted in increased surface runoff and flood flow. The study revealed a twofold impact of the development in the natural hydrology of the Shawsheen. Increased surface runoff flows quickly and causes significant flooding in this watershed. In the meantime, elevated surface runoff reduces the amount of water available to infiltrate into the soil system, reducing the amount of baseflow needed to feed the river system during dry weather. Therefore, the solutions to flood mitigation without considering baseflow reduction may not yield environmentally sound solutions to the issues in the Shawsheen watershed. According to Schuler (1994) stream classification, many sub-watersheds in the Shawsheen watershed can be classified as “impacted streams”. In this stream class, the impacts can be mitigated to the maximum extent possible by using effective Best Management Practices (BMP) such as infiltration basins, bio-retentions or rain gardens, detention basins, green roofs, and pervious parking. Therefore, proper management and environmentally sound planning are indispensable to protect the watershed from further degradation. Although scientifically sound and environmentally sustainable solutions were important in the Shawsheen watershed, it required further changes to stormwater regulations and policy and decision-making practices in the watershed. The regulations, in many municipalities in the watershed, mandated the reduction of the peak flow and runoff volume for all new and redevelopments. However, the regulations did not mandate the increase in groundwater recharge. The water balance study findings revealed that groundwater recharge was an important requirement to restore the Shawsheen River, especially needed flow during the dry period. Therefore, the policy changes were necessary to minimize the impact of further development.

Problem Recognition: Education and Outreach

Sub-watershed wide water balance modeling study provided the insight into the current hydrological situation of all 13 sub-watersheds in the Shawsheen River Watershed. Overall, the Shawsheen watershed was significantly lacking in its groundwater contribution due to the excess surface runoff as a result of development in this watershed. By collectively recognizing the imbalances in flow, SWT has decided to carry out two major actions towards the flow issue as follows.

- Education and Outreach: Educate the stakeholders, especially the municipalities, the state of the flow issue in Shawsheen and potential solutions.
- Detail Investigation: Investigate the selected sub-watersheds through detailed scientific studies towards identifying specific solutions.

Education and outreach effort was primarily to increase the awareness of the problem among stakeholders and stimulate decision makers and policy makers towards decisions to improve the existing flow conditions and to prevent the Shawsheen watershed from deterioration. A watershed wide workshop was conducted and the following elements were included in the agenda:

- Hydrological balances, current and pre-development, of Shawsheen River watershed and its tributaries
- Ongoing and historical flood solutions and the relationship with baseflow issue in the Shawsheen
- Potential solutions to mitigate flooding while improving the baseflow
- Planning tools and proposal for policy change to protect the Shawsheen

It was understood that a few sub-watersheds in the Shawsheen, especially sub-watersheds with excess urbanization, yield little or no baseflow during the late summer and early fall. This puts the Shawsheen River, a perennial stream, in danger to become a seasonal stream. The decision makers, planners, and engineers in the watershed have limited resources available to understand the impact of future development on watershed baseflow. In order to help stakeholders, SWT has decided to develop policies and tools to protect the Shawsheen watershed. The municipalities in the watershed have agreed to adopt no net increase policy in stormwater runoff. It requires that all the new and redevelopments in the watershed to implement best management practices (BMP), such as infiltration or detention of excess stormwater runoff, to control the excess stormwater runoff generated due to the development to mimic the hydrology of pre-development. Due to the complexity of understanding the impact of baseflow, SWT accepted and adopted the linear relationship between percent imperviousness and watershed baseflow (Saravanapavan et al., 2004) as a tool to understand the impact on natural hydrology as a result of new development and redevelopment without investing time and money on detailed assessments. The relationship was to be employed to quantify the objectives of BMPs, such as the volume of runoff to be recharged. For example, if a proposed development in a sub-watershed increases the imperviousness and decreases baseflow, one can easily estimate the amount of required infiltration using BMPs to avoid the negative impact of proposed development. Later, the policy was amended as "no net runoff to mimic pre-development hydrology." In this way, the solution in controlling excess runoff resulted in not only peak saving and detention but also infiltration and recharging the groundwater.

Problem Investigation and Implementation Planning

As a result of the water balance analysis, SWT decided to pay immediate attention to manage the stormwater at Hanscom sub-watershed. This was mainly because the contribution of surface runoff to stream flow doubled in this sub-watershed due to extensive developments. A hydrology network model was developed and calibrated at the Hanscom sub-watershed (Saravanapavan, 2001). The purpose of this model development was to quantify the stormwater runoff at the Hanscom sub-watershed. The model was also employed to evaluate and recommend solutions to control the flooding and water quality problems associated with the stormwater.

Overall, detailed flood analysis revealed that the rate of peak flow was increased to 4.3 times and 2.9 times for one and two-year design storms. It also revealed the volume of runoff was increased by 2.7 and 2.4 times during the one and two year design storms respectively. The substantial changes could easily explain the severe floods observed in 1996 and 1998 in this watershed (EOEA, 2003a). The recognition of the increased peak flow and flood flow, along with the ecological impacts to be discussed in detail later in this section, resulted in developing detailed restoration activities in this sub-watershed. It also helped SWT to seek funding for different sources such as Raytheon, other than government sources, to address the issues (EOEA, 2003a).

Problem Solving and Implementation Activities

The studies and investigations have provided SWT a clear picture of the problems on the Shawsheen related to flooding and low flows. Detailed investigation helped SWT to understand the magnitude of the problem and to quantify the solution to mitigate the problem. Regarding the flooding issue at Hanscom, SWT made a decision that the implementation would be along with the implementation solution of aquatic life impairment. Because through an innovative planning approach, SWT addressed the issue in parallel with flooding and resulted in numerical targets for low flow and flood flow. For the rest of the Shawsheen, SWT adopted "no-net" runoff policy for all redevelopment and new development projects.

As demonstrated through the process of addressing hydrologic issues in the Shawsheen watershed, the new management framework was followed closely in identifying the effective solutions. All major steps of addressing the issues in the framework, namely the problem identification, problem recognition, problem investigation implementation planning, and problem solving implementation actions, were all mobilized and integrated into the systematic problem-solving approach. The process eventually led to the employment of watershed imperviousness as a planning level tool, which can be directly used as a powerful aid to the policy-making process due to its simplicity. In addition, the process of correcting the hydrologic issues also demonstrated how science could play a critical role in persuading stakeholders to accept the physical truth and thus to address the actual causes directly. Another important conscience among SWT members was that further investigation and implanting solutions should be tied into another issue of habitat destruction that is presented next. It is important to note that the funding and technical support came from two different agencies, MA DEM for flooding and MA DEP for habitat issue. However, addressing these issues under the new framework paved way to have a meaningful interdisciplinary approach for two different issues.

Stakeholder Engagement in Addressing Flooding Issue

Urbanization and associated impacts resulted in frequent floods in Shawsheen River Watershed. In addition, a significant drought was observed during the summer of 1999, during which a few segments of the Shawsheen River primarily used for recreational activities almost dried up in this summer (EOEA, 2003a). Other than the physical observations and experiences, SWT had no scientific evidences and support to bring the involvement of local decision makers and government agencies together to address the issue. Also, there was a conflict among stakeholders in accepting low flow is an issue as well as the sources and causes of flooding problem. SWT launched several efforts, including scientific studies, major decisions, conflict resolutions, and acquiring external support, in order to solve the hydrological issues. Figure 4-13 summarizes all these effort that was carried out through 3C approach in a set of steps. Due to the limited hydrological and scientific knowledge among all stakeholders, a Technical Advisory Committee (TAC) was formed to provide peer review on the studies and outcomes (Saravanapavan et al., 2000). TAC consists of engineers and scientists from SWT and outside experts. Table 4-9 provides the details on TAC.

Table 4-9. Details on TAC that provides the oversight on technical studies.

Name	Organization	SWT Membership
Ms. Barbra Blumeris	Hydrologist, US Army Corps of Engineers	External Expert
Mr. Bill Dunn	Executive Office of Environmental Affairs	SWT – Watershed Team Leader
Mr. Brian Moore	Town Engineer - Andover	SWT
Mr. Dennis Verdi	Engineer, Natural Resources Conservation Service	External Expert
Mr. Donald Morris	Engineer, USAF	SWT
Mr. Gerry Girouard	Hydrologist, USGS	SWT
Ms. Holly Palmgren	Environmental Scientist, Raytheon Systems Company	SWT
Mr. John Libsy	Town Engineer - Billerica	SWT
Mr. Keith Beasley	Engineer, Massport Authority	SWT
Mr. Mike Gildesgame	Engineer, Dept. Environmental Management	External Expert
Prof. Neil Fennessey	University of Massachusetts Dartmouth	External Expert
Mr. Richard A Warrington	Town Engineer - Bedford	SWT
Mr. Richard Laramie	Engineer, Camp Dresser & McKee Inc	External Expert
Mr. Syamal Chaudhuri	Town Engineer - Burlington	SWT
Mr. Tom Fiorello	Town Engineer - Tewksbury	SWT

Towards understanding the flow issues at the watershed and to resolve the conflict of opinion, a hydrology balance investigation was launched (Saravanapavan et al., 2000). The study revealed substantial reduction in watershed base flow and increase in surface runoff, especially in highly developed sub-watersheds. It helped to resolve the stakeholder conflict and shifting the focus of flood mitigation efforts from conventional hydraulic solutions to watershed-based solution to address low flow and flood flow issues simultaneously. The study introduced a simple tool (Saravanapavan et al., 2004) to understand the impacts of base flow and assisted SWT in planning best management practices (BMP) to address such impacts. SWT conducted an educational campaign to spread the understanding throughout the watershed. A workshop was conducted to educate municipal officials on watershed-based flood solutions and to introduce innovative BMPs and practices that would increase infiltration while reducing the magnitude of peak flow and the volume of surface runoff. It stimulated local legislators and municipalities and other decision makers to understand watershed-based flood mitigation and no-net runoff policy towards proposing to adopt the policy in all redevelopment and new development projects. SWT also conducted further investigations (Saravanapavan, 2001) at the worst impacted sub-watershed in the Shawsheen headwaters of Hanscom, where the baseflow was reduced by fifty percent due to urbanization (Saravanapavan et al., 2000). These investigations made HAFB, an active member and contributor of SWT, to develop a long-term stormwater management plan to minimize the runoff generation and to maximize the groundwater recharge by following the planning principles adopted by SWT. The Massachusetts Port (Massport) Authority, another SWT member, also begun to implement BMPs in Hanscom airport to minimize the adverse impacts of stormwater flow. Through the interdisciplinary approach in addressing all issues simultaneously, the addressing of aquatic life impairment also resulted in similar recommendation to flooding and low flow issue. As a result, SWT decided to implement solutions to address flooding, low flow and aquatic life impairment through a single implementation plan that is presented with aquatic life issue in the next section.

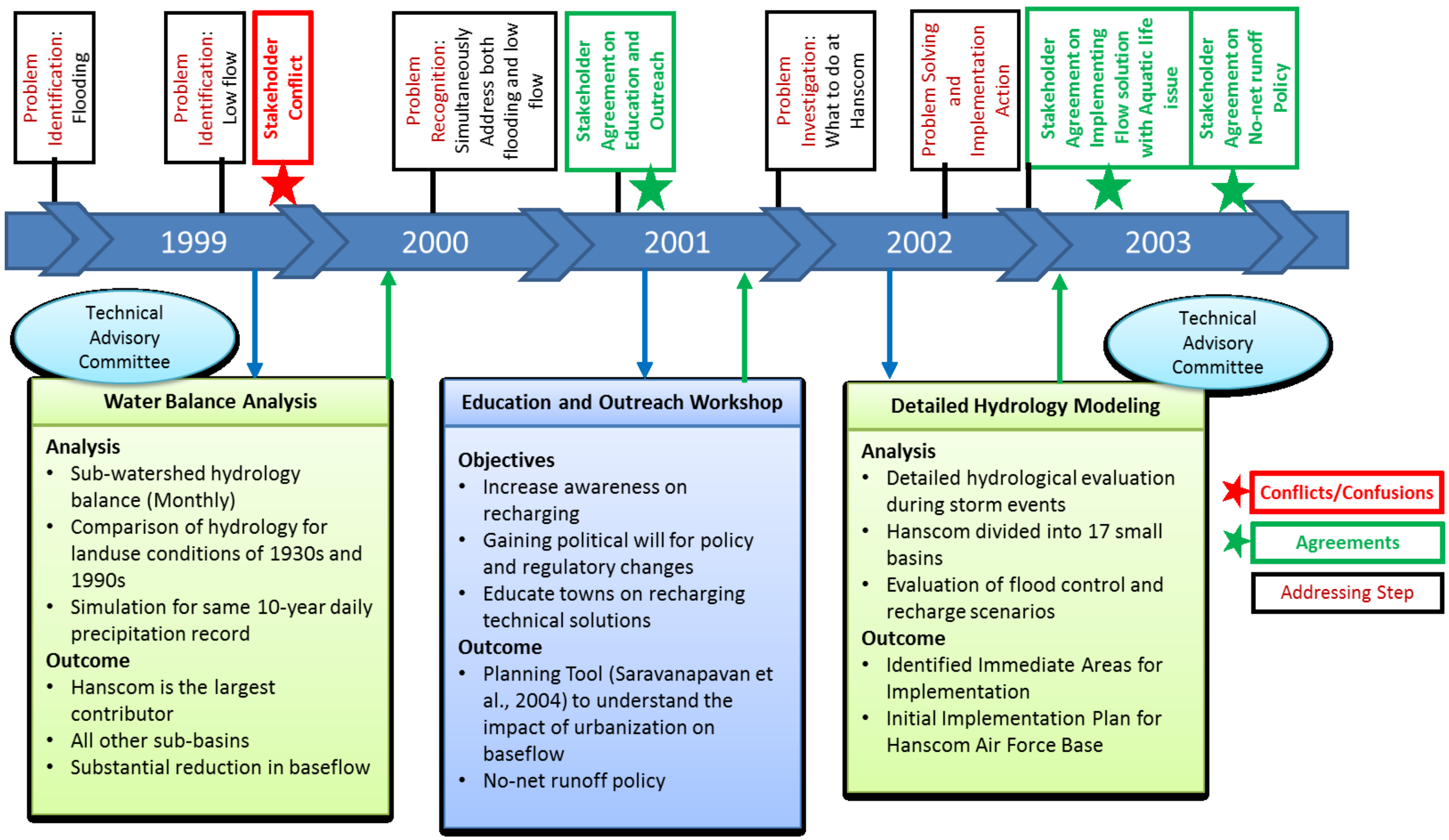

Figure 4-13. Addressing Flooding Through Hybrid Planning: Steps, Decisions and Timeline

4.4.2 Aquatic Life and Habitat Impairment

To effectively address the aquatic life and habitat issue and restore the impaired headwaters, the SWT deemed that a watershed-wide approach was necessary bring the stakeholders together to make appropriate decisions related to this impairment. The SWT has launched several efforts including data collection and analysis, Total Maximum Load Development (TMDL), planning restoration efforts, and educating the local officials and decision makers to integrate these understanding in practice (EOEA 2003a). This section investigates how SWT addressed the issue through 3C approach in every step of the decision making process (Figure 4-14).

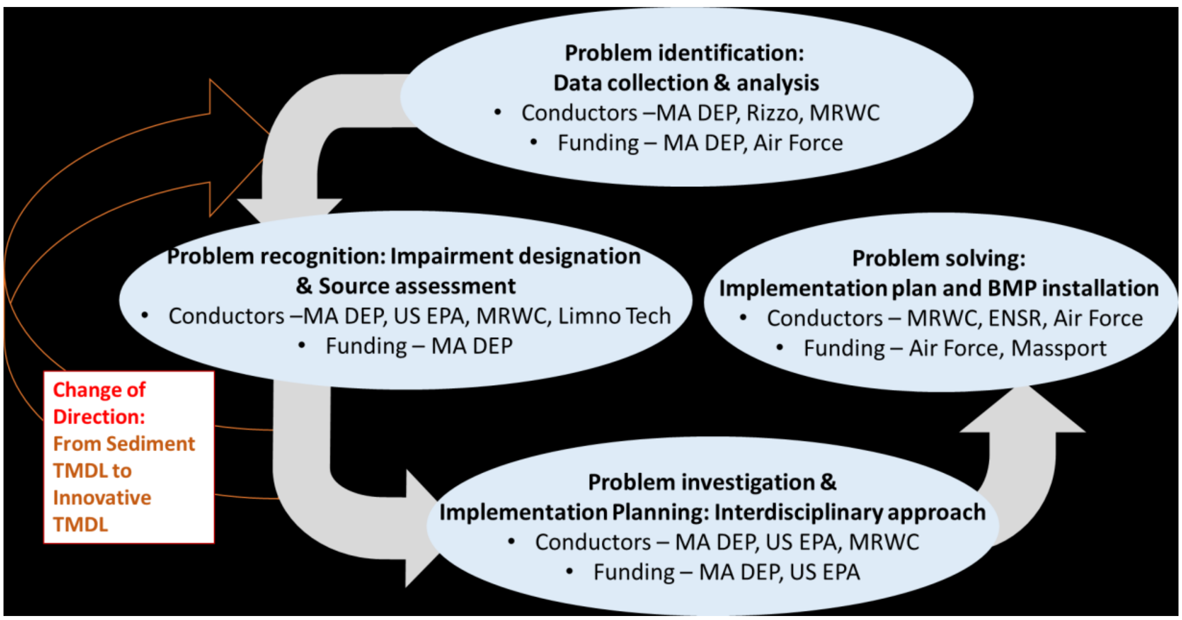

Figure 4-14. Addressing habitat and aquatic life issue through a systematic cycle of steps under the new management framework at Shawsheen.

Problem Identification: Data Collection and Initial Analysis

Among the SWT members, there was a common understanding that the Shawsheen headwaters had been significantly impaired due to the lack of aquatic life community and healthy habitat. However, there was a significant disagreement among the SWT members on the sources and causes of the impairment. Except a study by United States Air Force (Rizzo, 1996), there was little data and information available to validate the SWT's concern on aquatic life impairment and the sources and causes to further address the issue toward restoration. Therefore, SWT set that the objective of initial data collection and analysis (MRWC, 1997, 1998) was to confirm and to understand the severity of the aquatic life and habitat impairments at the Shawsheen headwaters.

All the initial data collection (Rizzo, 1996; MRWC, 1997, 1998) and assessment confirmed that the significant aquatic life impairment had existed in the Shawsheen headwaters. The studies further identified that the impairment was partially associated with sediment deposition along with channelization, etc.

Problem Recognition: Impairment Designation and Source Assessment

By collectively understanding and recognizing the aquatic life and habitat impairment in the headwaters of the Shawsheen, SWT has decided to address the issue towards restoring the impaired segment. As a result, SWT decided to address the issue in two ways: (1) To work with Massachusetts Department of Environmental Protection (DEP) to include the headwater as an impaired water body under the Section 303(d) of the Clean Water Act, and (2) To examine the sources and causes towards developing a restoration plan that guide the actions necessary to restore the impaired segment.

Section 303(d) of the Clean Water Act requires States to report all impaired or threatened water bodies that are not meeting water quality goals, despite the application of required technology based control measures, to the United States Environmental Protection Agency (EPA). Furthermore, Section 303(d) requires States to develop Total Maximum Daily Loads (TMDLs) for each 303(d) impaired water body. TMDL is a watershed restoration or cleanup plan that sets a pollutant cap. The cap is a formula that represents the maximum amount of a pollutant that a water body can receive and still meet the water quality standards. The Upper Shawsheen headwaters were listed on the 1998 Massachusetts 303(d) list, which was approved by EPA. The major reason behind SWT's attempt to include the Shawsheen headwaters was that it would increase the funding opportunity to plan and implement actions necessary to restore the river. For example, the state was responsible for developing TMDLs for impaired waters under the Clean Water Act. If the segment was listed, the state would allocate funding to develop TMDL. Once the TMDL is developed and approved, the municipalities and entities that discharge into the impaired segment are responsible for meeting the goals and objectives of the TMDL through stormwater permits. By recognizing the impairment through the regulatory process, SWT expanded the funding and scientific resources to address the issue in addition to its own annual funding.

SWT launched the effort to develop sediment TMDL as per the advices from US EPA and MA DEP believing that the sediment would be the major cause of impairment after initial data collection and analysis. After several attempts, SWT could not track sediment sources that could be linked to the impairment. It resulted in abandoning the effort of developing sediment TMDL with the bit of confusion on how to proceed further.

It was clear that there were multiple stressors involved in the impairment. However, there was not enough information to understand the relative contribution of each stressor and to link the sources and causes of the problem. The headwater of the Shawsheen River is a Class B freshwater, as identified under Massachusetts Water Quality Standards and has a designated use of Aquatic Life. However, the headwater of the Shawsheen River had been assessed by SWT and Massachusetts DEP as not fully supporting a healthy aquatic life community that was consistent with the narrative criteria in Massachusetts Water Quality Standards. While in confusion state, the same stakeholders had been addressing the flooding and low flow issue with the same forum. It gave SWT to understand the imbalances in hydrological regime at Hanscom sub-watershed. Based on extensive data and modeling analyses, and an inventory of potential pollution sources, a combination of several factors were identified as potentially causing non-attaining aquatic life uses. These factors include contaminants associated with stormwater runoff (e.g., sediments, metals, etc.), excessive storm water flow rates, and insufficient stream flow rates that was confirmed in the hydrological studies. It helped to clear the confusion that stormwater would be the major source. However, the confusion remained on how to address stormwater within TMDL program.

The overall focus of SWT was to develop a restoration plan to address the aquatic life impairment. The team recognized that developing a TMDL was an appropriate avenue to address this issue. TMDL development in this case was a challenge as no conventional pollutants, such as sediment, bacteria, nutrient, or metals, which have the history in TMDL development, were directly associated with the impairment. In cases where there are multiple stressors contributing to aquatic life impairments, it is very difficult to meaningfully identify appropriate loading capacities for each individual stressor within the conventional TMDL process. This unique situation lead SWT to seek an innovative approach to develop a restoration plan, to address the aquatic life and habitat issue through TMDL process.

Problem Investigation and Implementation Planning: Interdisciplinary Approach

Urbanization in a watershed generally results in an unfavorable environment for the natural river eco-system. These urban impairments are often associated with multiple stressors. As earlier mentioned, the multiple stressors believed to be impacting aquatic life/habitat impairment in the Shawsheen headwaters included contaminants associated with storm water runoff (e.g., sediments, metals, etc.), hydrologic modifications (excessive and insufficient stream flow rates), riparian corridor encroachment (the area and landscaping adjacent to the stream), and channel alteration (Saravanapavan et al., 2014). These stressors may be acting either in an individual or cumulative manner to cause the impairment. SWT had little or no information to determine the exact role and significance that each pollutant/stressor plays in contributing to the impairment to habitat and aquatic life. However, based on available information it could be safely inferred that the impairments were related to extensive development of the watershed and all the stressors are associated with a common cause - stormwater runoff. In addition to contaminated stormwater runoff, frequently occurring high flows resulting from high runoff rates from impervious areas, adversely impacted aquatic organism survival and reproduction due not only to the poor quality of the runoff but by physical washout, decreasing channel stability, and destroying useful habitat through scouring or excessive sediment deposition. Conversely, substantial reductions in stream base flows associated with increased imperviousness reduced habitat abundance and increased the concentration of pollutants. Elevated water temperatures are often associated with decreased flows because of shallower flow depths in the stream channel and the reduction of cooler groundwater entering the channel which typically comprises most of the stream's base flow.

Unlike a TMDL for a traditional pollutant (such as sediment, nutrients, or bacteria), it was very difficult to meaningfully identify critical conditions and the appropriate loading capacities for each individual stressor associated with habitat/aquatic life impairments. Sufficient data/information and knowledge were not available to SWT to isolate the relative strength of each stressor and to link each stressor independently to the impairment. As a result, developing a TMDL for habitat/aquatic life impairments presented unique and complex challenges. It required innovative approach to develop a TMDL that would address such impairments and also be the basis for implementing control actions. The impairments, in many cases, were related to excessive development in the watershed and the stressors are largely associated with a single source category such as stormwater runoff. SWT introduced an innovative approach (Saravanapavan et al., 2014) using storm water as an umbrella surrogate for all stressors contributing to the aquatic life impairment in the Shawsheen headwaters. Also, this approach provided the necessary information to meaningfully guide storm water management implementation activities since many of the available storm water controls were capable of addressing excessive runoff rates and multiple pollutants. The use of surrogate indicators expressed as quantitative targets is an important tool for developing this type of TMDLs. The approach utilized flow duration statistics to identify a suitable surrogate hydrology target that supported healthy habitat/aquatic life. Details of the approach, which can serve as a general tool for effective watershed management in urban areas, are further discussed in Chapter 5.

Problem Solving and Implementation Activities: Best Management Practices

The introduction of an innovative approach to develop aquatic life and habitat TMDL for the Shawsheen initiated many activities among the SWT members. Along with SWT, MA DEP developed a TMDL (DEP, 2003) to address the aquatic life and habitat impairments in the Shawsheen headwaters. As a part of the TMDL process, a draft TMDL was developed. MA DEP has carried out a public outreach effort, including public town meeting followed by public comment processes. SWT adopted the targets identified (to increase low flow and decrease flood flow) and set the goals of storm water management for this sub-watershed and HAFB, which owns the two-thirds of the drainage area in the sub-watershed. It is important to note that the identified implementation targets were not only addressing the habitat and aquatic life impairment, but also it was simultaneously addressing the flooding and baseflow issue. As a result, it was welcomed by all members of SWT without any objection. In order to achieve these goals, SWT decided to install best management practices. SWT conducted a detailed examination (Saravanapavan, 2002) to identify and select appropriate best management practices (BMP) to successfully meet the hydrological targets set by the TMDL, which was to reduce the high flow or flood flow (5% flow) by 47% and to increase baseflow (95% flow) by 82% for the Hanscom sub-watershed at the Shawsheen headwaters. To accomplish this objective, SWT has identified the following BMPs categories:

- Recharge/exfiltration BMPs,

- Low impact development strategies, and
- Extended detention BMPs.

Recharge BMPs are designed to infiltrate collected stormwater into the ground. These BMPs include surface systems, such as retention basins, and underground systems, such as infiltration galleys and leaching catch basins. These systems are typically installed at the end of a stormwater collection system and operate by temporarily storing stormwater and allowing it to percolate into the ground. Siting of recharge BMPs is primarily dependent on two factors: soil hydraulic conductivity and groundwater elevations. Effective recharge systems must be located in soils with sufficient permeability to allow groundwater to recharge between storm events. Generally, a hydraulic conductivity of 1.27 cm/hour or greater is desired for recharge BMPs. Effective recharge systems must also be located with sufficient vertical separation from the groundwater table. A minimum separation of 60 cm between the bottom of the recharge BMP and the seasonal high water table is recommended. However, a greater separation is desirable to prevent a groundwater mound that intersects the bottom of the recharge system, since once this occurs, recharge rates are significantly reduced.

Low impact development (LID) strategies are defined by USEPA (2000) as a site design strategy with a goal of maintaining or replicating the pre-development hydrologic regime through the use of design techniques to create a functionally equivalent hydrologic landscape. Hydrologic functions of storage, infiltration, and ground water recharge, as well as the volume and frequency of discharges are maintained through the use of integrated and distributed micro-scale stormwater retention and detention areas, reduction of impervious surfaces, and the lengthening of flow paths and runoff time. Other strategies include the preservation/protection of environmentally sensitive site features such as riparian buffers, wetlands, steep slopes, valuable (mature) trees, flood plains, woodlands and highly permeable soils.

Extended detention BMPs are designed to detain stormwater flows for an extended period following storm events. The volume of stormwater discharged will not be reduced as with a retention system, but if the flows are spread out over a long enough period, then the high flow rate will be reduced. For example, vegetated wetlands are natural extended detention BMPs. While retention type BMPs may be preferable from a groundwater recharge standpoint, extended detention BMPs may be more suited to soil and groundwater conditions found at HAFB. These types of BMPs are generally better suited for long-term viability than recharge-type BMPs which are subject to obstruction over time. An effective extended detention BMP for HAFB could be wetland/extended detention basins.

According to the Massachusetts state stormwater handbook, the implementation of all the three types of BMPs are subject to certain site constraints such as surface slope, wetland locations, soil conditions, and land use/land cover (Saravanapavan, 2002). The SWT performed a desktop analysis to identify potential sites for BMP implementation. The potential sites were then submitted to a quarterly meeting for review, in combination with verification results from field survey. Based on the field survey, SWT review, and USAF engineering unit inputs, the locations and types of the BMPs were finalized and were selected for design and construction (Figure 4-15).

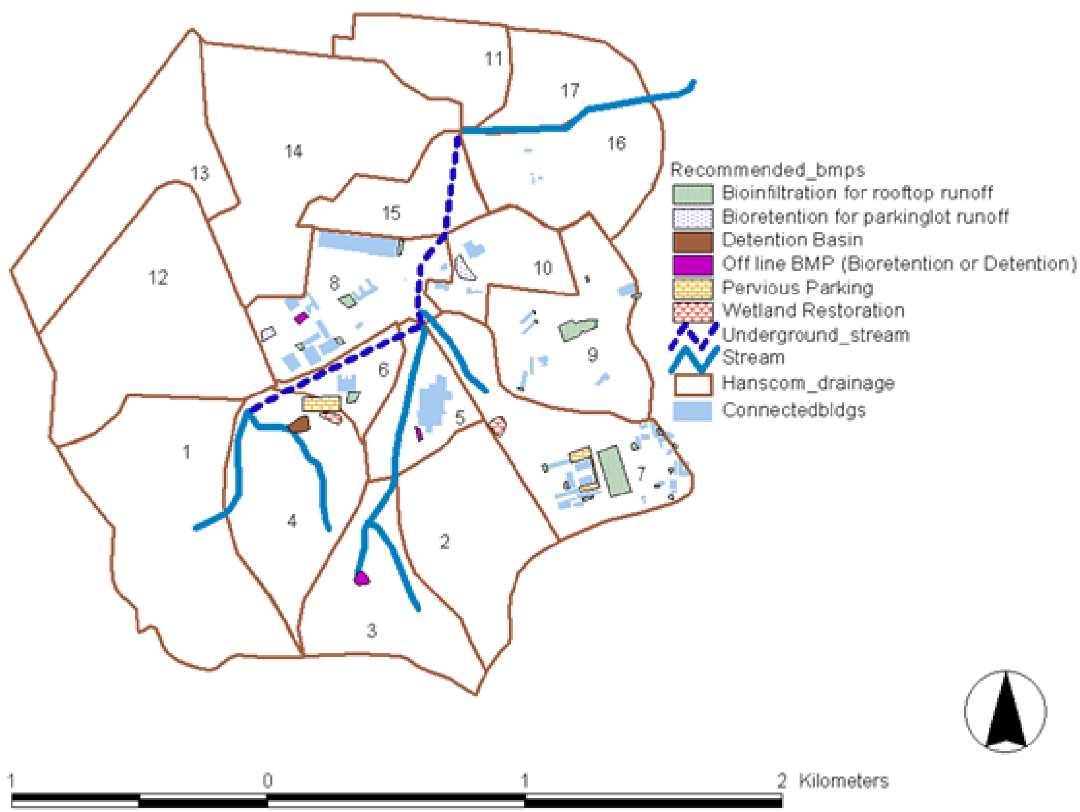

Figure 4-15. Final list of selected BMPs to be located at the Hanscom US Air Force Base to meet the goals of the Shawsheen headwater TMDL.

Stakeholder Engagement in Addressing Aquatic Life Issue

To effectively address the aquatic life and habitat issue and restore the impaired head-waters, SWT deemed that a watershed-wide approach was necessary to bring the stake-holders together to make appropriate decisions related to this impairment. SWT addressed this issue through 3C approach in a set of steps, problem identification, problem recognition, implementation planning and policy adoption, and problem solving and implementing actions. SWT's effort in addressing the aquatic life and habitat impairment, including steps, decisions, agreements and confusions, are presented in Figure 4-16.

Data collection in the Shawsheen headwaters documented habitat and aquatic life impairments and that resulted in placing a three-kilometer headwater river segment in the impairment list of Massachusetts 303 (d) list. Subsequent comprehensive data collection (MRWC, 1999) by SWT confirmed the existence of these impairments. The overall focus of SWT was to develop a restoration plan. The team recognized that developing a Total Maximum Daily Load (TMDL) was an appropriate avenue to address this issue. At one stage during problem recognition step, it was abandoned in developing sediment TMDL due to the inability to link the problem to sediment sources in the watershed. Then it created a confusion on the next step to proceed. The confusion resulted in an innovative approach to develop TMDL. As a result, a new innovative approach (Saravanapavan et al., 2014) was introduced to use hydrology as an umbrella to address all stressors associated with the main source, stormwater, for aquatic life impairments in urban environment. As a result, a TMDL (MADEP, 2003) was developed. SWT adopted the targets identified and set the goals of stormwater management for the headwater sub-watershed. The selection of the hydrology as surrogate, as well as the identification of BMP implementation candidate sites (Saravanapavan, 2002) all relied heavily on the scientific analysis on subjective areas. The solid knowledge regarding the relationship between the flow duration curve and the ecologic consequences, as well as the relationship between site characteristics and long-term BMP performances, ensured that the identified BMP solutions would achieve sustainable watershed management objectives in the Shawsheen watershed.

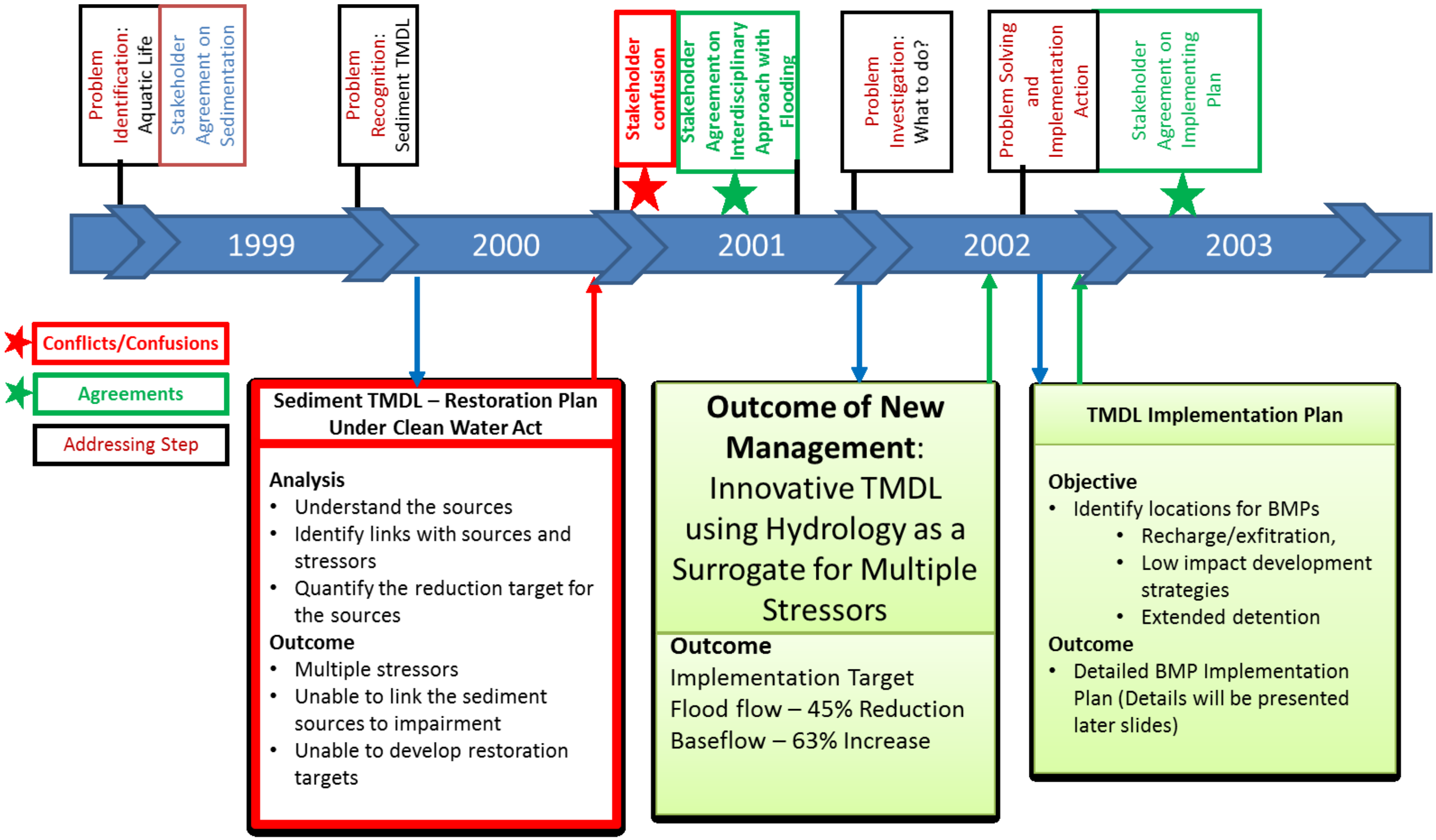

Figure 4-16. Addressing Aquatic Life/Habitat Impairment Through Hybrid Planning: Steps, Decisions and Timeline

4.4.3 Bacteria Impairment

The Shawsheen River was placed on the State of Massachusetts' 303 (d) list of impaired water bodies for pathogens (MA DEP 1999). Within the Shawsheen River Watershed, state fecal coliform standards were exceeded for class B waters. As defined in 314 CMR, Massachusetts Surface Water Quality Standards, Class B waters are designated as habitat for fish, other aquatic life, and wildlife, and for primary and secondary contact recreation. The state standards specify that the maximum allowable concentration of fecal coliform bacteria shall not exceed a geometric mean of 200 organisms per 100 ml in any representative set of samples, nor shall more than 10% of the samples exceed 400 organisms per 100 ml. Bacteria impairment and related issues have been felt and addressed by the state and local agencies (MA DEP, 1990, 1996) before the formation of the Shawsheen Watershed Team (SWT). Therefore, when SWT was formed, one of the goals of SWT was to reduce bacteria loading in the Shawsheen River and its tributaries to meet the Massachusetts Water Quality Standards and remove the listed sections of the Shawsheen from the 303(d) list for bacteria through continuous and collaborative efforts under the Massachusetts Watershed Initiative (MWI).

To effectively address the bacteria impairment throughout the watershed, the SWT deemed that a watershed-wide approach was necessary to bring the stakeholders together to make appropriate decisions and actions related to this issue. The SWT has launched several efforts, including data collection and analysis, Total Maximum Daily Load (TMDL) development, planning restoration efforts, educating the local officials and decision makers, and integrating these understanding into practice (EOEA, 2003a). This section investigates how SWT addressed the issue through 3C approach in every step of the decision-making process (Figure 4-17).

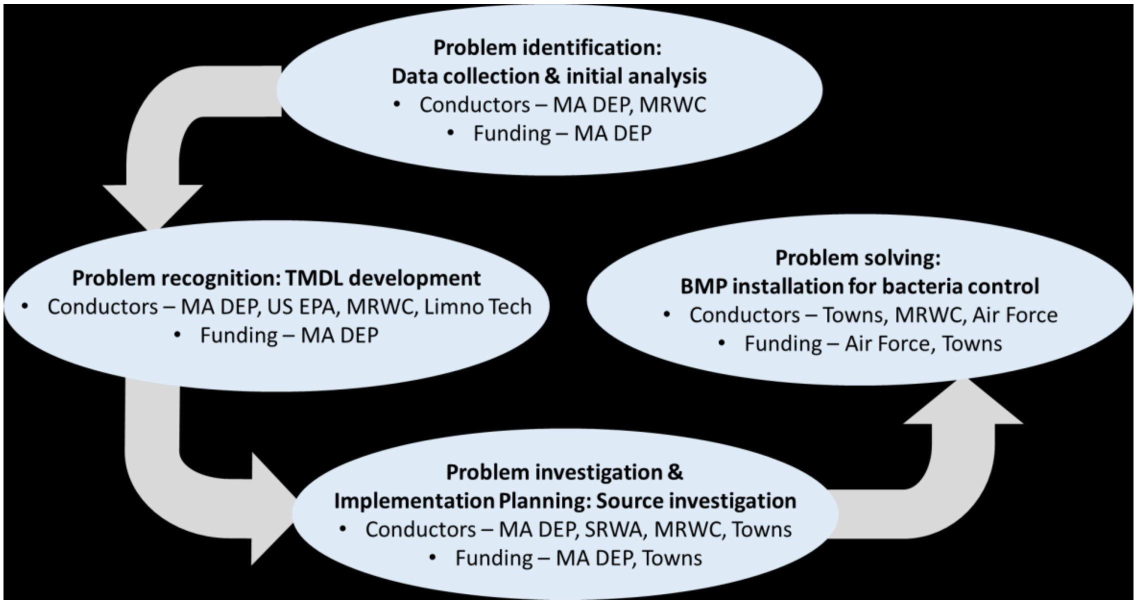

Figure 4-17. Addressing bacteria issue through a systematic cycle of steps under the new management framework at Shawsheen.

Problem Identification: Data Collection and Initial Analysis

High levels of fecal coliform bacteria have been recorded throughout the Shawsheen watershed as a result of the urbanization process. The entire Shawsheen River appeared in the "Final Massachusetts Section 303(d) list of waters - 1998" (MA DEP, 1999), due to bacteria impairment. Among the SWT members, there was a common understanding and agreement on the bacteria impairment. Since the issue was given enough priority by SWT members before the formation of SWT, it was the first issue that SWT members had wanted to address. SWT has decided to address the issue through regulatory processes, such as TMDL. In order to confirm the impairment and to identify the sources and causes, SWT has decided to conduct an initial analysis of data available. The objective of initial data analysis was to confirm and to understand the severity of the bacteria issue. Also, the initial data analysis focused on identifying data gaps to address the issue through TMDL process.

The Shawsheen River and its tributaries have been monitored for fecal coliform since 1989. The database used for the initial analysis contains over 1,200 fecal coliform samples collected by both the Massachusetts Department of Environmental Protection (1990 and 1996) and the Merrimack

River Watershed Council (1996, 1997, and 1998). All fecal coliform data were collected between the months of June and October. Overall, initial data analysis gave SWT a much more comprehensive view of bacterial contamination throughout the watershed. SWT has decided to use these available data to develop a Bacteria TMDL for the Shawsheen River. TMDL is a watershed restoration or cleanup plan that sets a pollutant cap. The cap is a formula that represents the maximum amount of a pollutant that a water body can receive and still meet the water quality standards. Regulatory recognizing and potential funding support from federal and state government are the major reasons behind SWT's decision to address the bacteria impairment issue through TMDL processes.

Problem Recognition: TMDL Development

TMDLs determine the amount of a pollutant that a waterbody can safely assimilate without violating the water quality standards. TMDLs are comprised of the sum of individual waste load allocations (WLAs) for point sources and load allocations (LAs) for non-point sources and natural background levels. In addition, the TMDL must include a Margin of Safety (MOS), either implicitly or explicitly, that accounts for uncertainty in the relationship between pollutant loads and the quality of the receiving water body. Conceptually, this definition is denoted by Equation 4.1.

LC = TMDL = Sum of all WLAs + Sum of all LAs + MOS (Equation 4.1.)

The term LC represents the loading capacity, or maximum loading that can be assimilated by the receiving water while still achieving water quality standards. The overall loading capacity is subsequently allocated into the TMDL components of WLA, LA, and MOS.

The pollutant loading that a waterbody can safely assimilate is expressed as either mass per time, toxicity or some other appropriate measure (40 C.F.R. Section 130.2(i)). Typically, TMDLs are expressed as total maximum daily loads. However, SWT believed that it was appropriate to express bacterial TMDLs in terms of concentration because the fecal coliform standard was also expressed in terms of the concentrations of organisms per 100 ml. Since source concentrations may not be directly added, the previous equation (equation 4.1) does not apply. To ensure attainment with Massachusetts' water quality standards for bacteria, all sources (at their point of discharge to the receiving water) must be equal to or less than the standard. Expressing the TMDL in terms of daily loads is difficult to interpret given that the very high numbers of bacteria and the magnitude of the allowable load were dependent on flow conditions and, therefore, would vary as flow rates change. For example, a very high number of bacteria are allowable if the volume of water that transports the bacteria is high too. Conversely, a relatively low number of bacteria may exceed water quality standards if flow rates are low. For all the above reasons, the TMDL is simply set equal to the standard and expressed as follows (Equation 4.2):

TMDL = Fecal coliform standard = WLA(p1) = LA(n1) = WLA(p2) = etc. (Equation 4.2.)

Where:

WLA(p1) = allowable concentration for point source category (1)

LA(n1) = allowable concentration for nonpoint source category (1)

WLA(p2) = allowable concentration for point source category (2), etc.

For Class B surface waters, the fecal coliform TMDL includes two components: (1) the geometric mean of a representative set of fecal coliform samples shall not exceed 200 organisms per 100 ml; and (2) no more than 10% of the samples shall exceed 400 organisms per 100 ml. The Shawsheen River and its tributaries are all Class B waters. The goal to attain water quality standards at the point of discharge was environmentally protective and offered a practical means to identify and evaluate the effectiveness of control measures. In addition, this approach established clear objectives that could easily be understood by the public and individuals responsible for monitoring activities. Also, the goal of attaining standards at the point of discharge minimizes human health risks associated with exposure to pathogens because it does not consider losses due to die-off and settling that are known to occur.

There was only one permitted point source discharger of fecal coliform within the Shawsheen River Basin. The fecal coliform permit limits for this discharger were: an average monthly concentration of 200 #/100 ml and a daily maximum concentration of 400 #/100 ml. A WLA set equal to the fecal coliform standard would be assigned to the Battle Road Wastewater Plant discharge. Based on a review of monthly operating reports, this facility was found to be in compliance with its permit limits and also in compliance with the fecal coliform water quality standard. Direct storm water discharges of fecal coliform from storm drainage systems also occurred within the Shawsheen

River Basin. Piped dischargers were, by definition, point sources regardless of whether they were currently subject to the requirements of NPDES permits. Therefore, a WLA set equal to the fecal coliform standard would be assigned to the portion of the storm water that discharges to surface waters via storm drains.

WLAs and LAs were identified for all known source categories including both dry and wet weather sources for all Class B segments within the Shawsheen River Basin. Establishing WLAs and LAs that only address dry weather bacteria sources would not ensure attainment of standards because of the significant contribution of wet weather bacteria sources to fecal coliform criteria exceedances. Leaking sewer lines and illicit sewer connections represented the primary dry weather point sources of bacteria, while failing septic systems represented the nonpoint sources. Wet weather point sources included discharges from storm water drainage systems, and pump station overflows. Table 4-8 presents the fecal coliform bacteria WLAs and LAs for each of the source categories. Source categories representing discharges of untreated sanitary sewage to receiving waters were prohibited, and therefore assigned WLAs and LAs equal to zero. The WLA and LA for stormwater discharging to the Shawsheen River and its tributaries were set equal to the fecal coliform standard for Class B waters.

Table 4-10. Fecal Coliform Wasteload Allocations (WLAs) and Load Allocations (LAs) for the Shawsheen River and Identified Tributary Streams.

Bacteria Source Category	WLA (organisms/100ml)	LA (organisms/100ml)
Point Source	Geomean ≤ 200 & 10% ≤ 400	
Sewer leaks	0	0
Sanitary Sewer Overflow	0	0
Illicit Sewer Connections	0	
Failing Septic Systems	0	0
Urban Stormwater Runoff	Geomean ≤ 200 & 10% ≤ 400	Geomean ≤ 200 & 10% ≤ 400

The TMDL should provide a discussion of the magnitudes of the pollutant reductions needed to attain the goals of the TMDL. Since accurate estimates of existing source contributions were generally unavailable, it was difficult to estimate the pollutant reductions for specific sources. For the illicit sources, the goal was complete elimination (100% reduction). However, overall wet weather bacteria load reductions could be estimated using typical storm water bacteria concentrations, as presented in Table 4-8, and the magnitude of the wet weather data observed in the Shawsheen Basin. This information indicated that 1 to 2 orders of magnitude reductions in stormwater fecal coliform loadings would be necessary.

Examination of wet weather data separately provides estimates of magnitudes of reductions from all sources during wet weather conditions. As indicated in Table 4-9, bacteria reductions of 1 to 2 orders of magnitude (e.g., 2,000 to 200 (1 order of magnitude); 20,000 to 200 (2 orders of magnitude)) were needed to attain water quality standards. For example, when viewing the data in Table 4-9 at Elm Brook, a reduction of 74% was needed to reduce fecal coliform levels to meet water quality standards during wet weather conditions. The 90% observation listed in the table means that 90% of the samples collected at this station fall below the value of 760 organisms per 100ml. That value would have to be reduced to 400 organisms per 100 ml to meet water quality criteria. This translates to a 47.4% reduction.

Table 4-11. Estimates of Fecal Coliform Loading Reductions to the Shawsheen River and Tributaries

Station	Elm Brook	Vine Brook	Rogers Brook	Upper Shawsheen	Lower Shawsheen
Wet weather Geo. Mean (mg/L)	770	2,700	5,126	32,863	2,491
% Reduction	**74.0**	**92.6**	**96.1**	**99.4**	**92.0**
Overall Geo. Mean (mg/L)	563	3,851	1,912	44,041	542
% Reduction	**64.5**	**94.8**	**89.5**	**99.5**	**63.1**
90% Observation (mg/L)	760	5,200	7,100	54,000	660
% Reduction	**47.4**	**92.3**	**94.4**	**99.3**	**39.4**

Although it was instrumental in bringing all the resources to develop Bacteria TMDL for the Shawsheen River, SWT had to rely on its members, MA DEP and US EPA, to move this process forward as a regulatory process. The summary of the regulatory processes is presented below.

- MA DEP drafted the initial legal TMDL document (MA DEP, 2002, dated Feb. 7, 2002), and submitted the draft to US EPA and made available for public review and comment.
- A public notice was issued by MA DEP for review, written comment, and public hearing on draft TMDL.
- A public hearing was conducted by MA DEP at Billerica Town Hall on March 12, 2002.
- A final draft TMDL was submitted by addressing public commenting and hearing process and US EPA's technical review comments in May 2002.

The Shawsheen TMDL became final with the approval from US EPA in August 2002.

Problem Investigation and Implementation Planning: Source Investigation

Although it was successful in developing and acquiring approval in TMDL process, SWT was limited by data availability to isolate and prioritize sources and causes with high bacteria contributions. It prevented SWT to begin implementation activities to control bacteria impairment in the Shawsheen. SWT was in a confusion mode on what to do next. After a lot of deliberation, SWT had launched a detailed source investigation to conduct sampling to understand the sources of bacteria, to identify and assess the sources, and to develop a strategy to address the control of sources and causes of the bacteria contamination in the Shawsheen River Watershed. Approved Shawsheen River Bacteria TMDL (MA DEP, 2002) identified point sources, septic system failures, and non-point urban sources as primary potential bacteria sources of bacteria in the watershed. Therefore, the detailed investigation was targeted to address these three identified sources.

Fourteen active minor National Pollutant Discharge Elimination System (NPDES) permitted point sources were reported in the Shawsheen River Watershed (Saravanapavan and Tasillo, 2003). Of these fourteen sites, one permitted facility had a fecal coliform limit (Battle Road Farm WWTP). The NPDES permit requires reporting on daily and monthly fecal coliform levels. The daily fecal coliform limit is 400 counts/100 ml and the monthly limit is a geometric mean of 200 counts/100 ml. Review of the point source records from 1998 to 2002 revealed that this facility had violated its permit for the parameter fecal coliform in March 2000 and June 2001. In March 2000, the daily fecal coliform limit was exceeded at 404 counts/100 ml and in June 2001 at 428 counts/100 ml. The other thirteen facilities did not have fecal coliform limits listed in their permits and were not considered to be significant contributors of bacteria. The investigation revealed that there was no major point source, especially from industrial and commercial activities, that has significant contribution of bacteria in the Shawsheen River.

Failing septic systems had the potential to deliver bacteria to surface and ground water if the system failed to provide treatment. Septic system failure occurs when wastewater breaks out or passes through the soil profile without adequate treatment (Schueler, 1999). Septic system failure can have many causes including improper design, installation and siting, or inadequate maintenance. The Commonwealth of Massachusetts regulates septic systems under the Massachusetts State

Environmental Code, Title 5, 310 CMR 15.00. Title 5 of the Massachusetts Environmental Code; "…provides for the protection of public health, safety, welfare and the environment by requiring the proper siting, construction, upgrade and maintenance of on-site sewage disposal systems and appropriate means for the transport and disposal of septic (310 CMR 15.00)". Revised in 1995, Title 5 requires inspection of private on-site septic systems before properties using them are sold, expanded or undergo a change in use. Systems that fail inspection are required to be repaired, replaced or upgraded to protect public health and the environment. Failing septic systems are required to connect to the sewer system (if available) or be repaired. If the sewer system is not available, the homeowner can have the town extend the sewer system and then connect. Local Boards of Health are responsible for regulating Title 5 with oversight from the state Department of Environmental Protection (DEP).

Stormwater was identified in the approved TMDL (MA DEP, 2002) as the greatest contributor of bacteria in the Shawsheen River. The TMDL recommended that additional wet weather data be collected to verify hot spots and prioritize storm drains. The storm water analysis in the TMDL was based on limited data that was not sufficient to isolate and prioritize drains. Among SWT members, there was an agreement that site specific investigations were needed to address these data gaps in order to isolate and evaluate major non-point bacteria sources and to identify control measures and/or necessary future steps to reduce bacteria in the Shawsheen River Watershed. SWT had launched a non-point source assessment (Saravanapavan and Tasillo, 2003). The assessment was designed to conduct a coordinated out-of-pipe fecal coliform monitoring throughout the Shawsheen River, to develop a detailed drainage area assessment to understand and isolate potential sources, and to recommend future actions toward bringing the understanding of non-point sources to the level of point sources in order to implement actions to control the bacteria impairment.

The overall bacterial impairment conditions in the Shawsheen River were assessed through sampling activities. As reported by Saravanapavan and Tasillo (2003), all sampling sites investigated for fecal coliform in the Shawsheen exceeded the state standard (Figures 4-18 & 4-19, Table 4-11). Among the sampling sites in the Lower Shawsheen, site AN 53 exhibited the highest geometric mean at 13,959 counts/100 ml. This site drained a single family residential area in the Rogers Brook tributary. Other sampling sites with excessive geometric means included AN 59 and AN 35 with geometric means of 5,413 and 2,928 counts/100 ml respectively. The drainage area of site AN 59 consisted of an impervious surface and site AN 35 drains a commercial parking lot. Elevated fecal coliform levels among the Upper and Middle Shawsheen sampling sites included sites BE 21A and BE 21B. These storm drain outlets were located adjacent to one another and drain a large impervious parking lot of a commercial shopping plaza. The recorded geometric means at BE21 A and BE 21B are 51,380 and 161,245 counts/100 ml respectively.

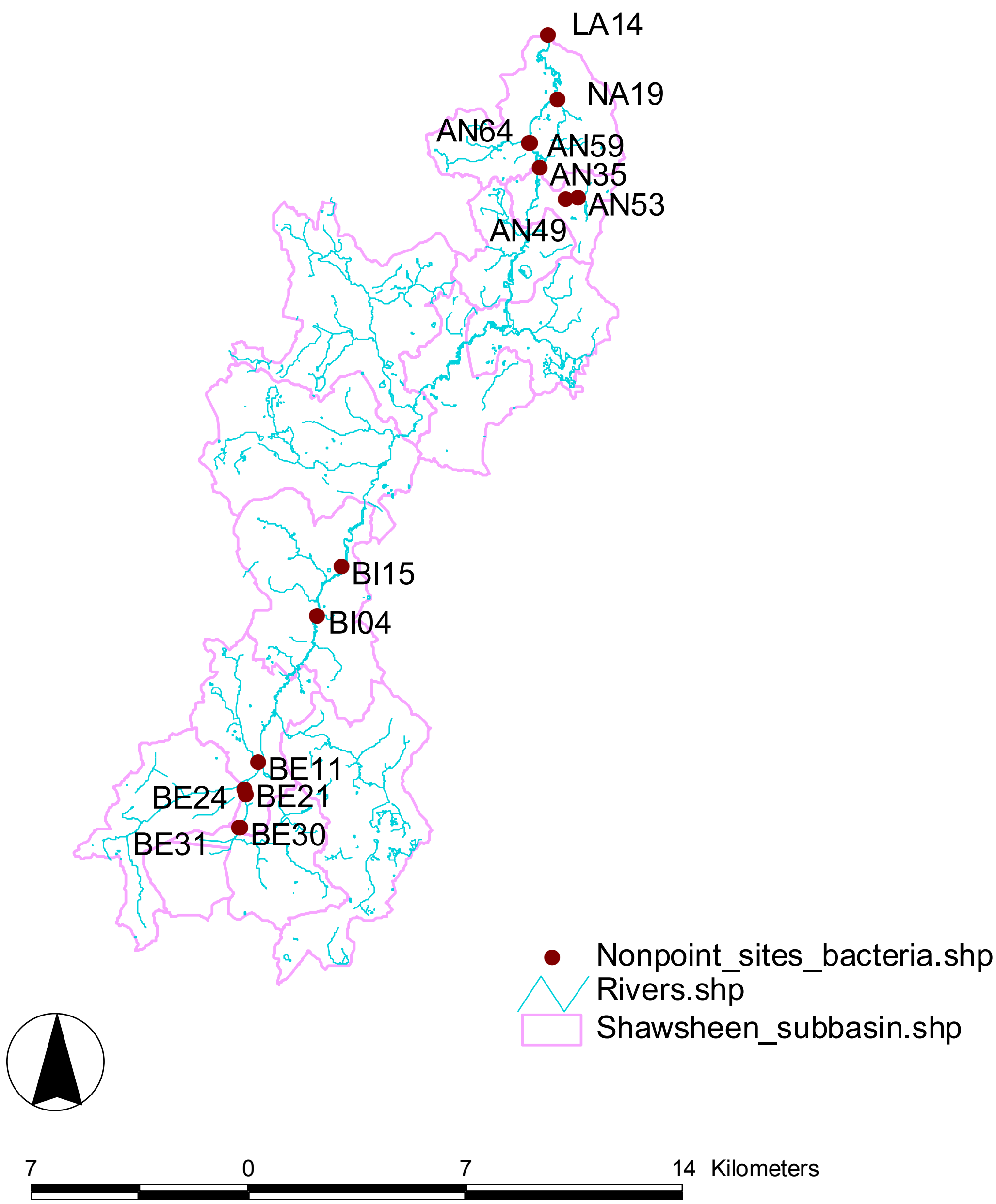

Figure 4-18. Location of sites where fecal coliform samples were collected as a part of non-point source investigation.

Table 4-12. Summary of Fecal Coliform Investigation (Saravanapavan and Tasillo, 2003a)

Site ID	Geometric Mean (Standard: < 200 counts/ 100 ml)	% above 400 (counts/100 ml) (Standard: < 10%)
AN35	2,979	100
AN64	495	67
AN59	5,413	100
AN49	632	100
AN53	13,959	100
LA14	837	75
NA19	1,439	60
BE11	13,834	100
BE21A	51,380	100
BE21B	161,245	100
BE24	12,002	100
BE30	317	67
BE31	305	75
BI04	24,000	100
BI15	60,000	100

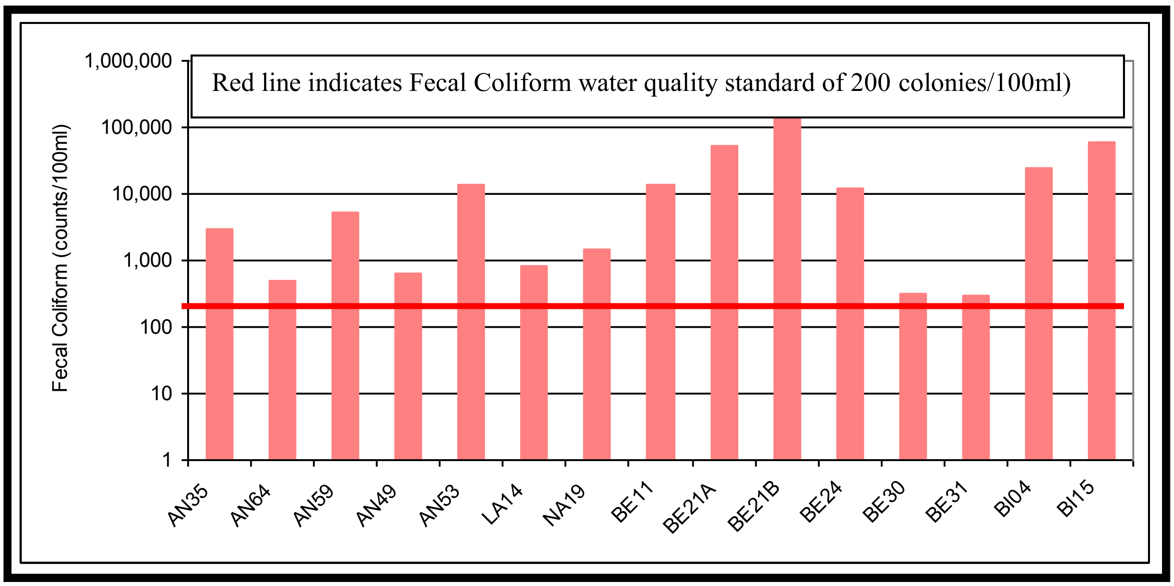

Figure 4-19. Sampled Fecal Coliform counts and geometric mean at Shawsheen Sites.

Among the fifteen sites sampled, eleven priority sites were chosen by SWT for further investigation. The selections of priority sites were based on elevated fecal coliform levels as well as sites with drainage basins representative of individual land uses. Sites that drain a representative land use can be used as a model to identify sources of fecal coliform concentrations in other communities.

The investigation by Saravanapavan and Tasillo (2003) revealed that bacteria contamination associated with non-point sources in the Shawsheen River Watershed was generally from poor storm water system maintenance, poor pollution prevention practice, pet waste, wildlife, runoff from impervious areas and non-storm water discharges. In order to control all of these sources, especially to implement structural BMPs that reduce bacteria input into the river and to further isolate sources, targeted investigation and monitoring was needed. However, there were control measures that could be implemented immediately, especially non-structural BMPs that manage the sources of bacteria identified in the detailed investigation. Table 4-13 provides the summary of initial recommended actions that SWT had begun addressing the bacteria impairment from non-point sources. Although the recommendations were provided to specific site, SWT recognized the applicability throughout the watershed where similar sources identified as the cause of the bacteria impairment.

Table 4-13. Specific Recommendations for Priority Sites.

Site ID	Potential Sources	Recommendation
AN 35	Sediment, sewer leaks/breaks	• Catch basin cleaning • Bacteria ribotyping
AN 59	Sediment, Pet waste, Wildlife, sewer leaks/breaks	• Catch basin cleaning • Street sweeping
AN 53	Pet waste, Sediment, sewer leaks/breaks	• Pet waste management and education • Investigate illicit discharges and sewer leaks/breaks
NA 19	Sediment, Pet waste	• Further storm drain sampling at suggested locations within the drainage area for E.coli and Fecal coliform.
BE 11	Pet waste, Sediment, Wildlife	• Catch basin cleaning • Street sweeping • Pet waste management and education
BE 21 (A&B)	Sediment, Infiltration Basin, Pet waste	• Further storm drain sampling for E.coli • Bacteria ribotyping • Catch basin cleaning • Investigation on the infiltration basin and its performance
BE 24	Sediment, Wildlife, sewer leaks/breaks	• Further storm drain sampling for E.coli • Bacteria ribotyping • Catch basin cleaning

		• Erosion control in the loading and unloading area • Investigate illicit discharges and sewer leaks/breaks
BE 30	Pet waste, Sediment, Wildlife	• Further storm drain sampling for E.coli • Bacteria ribotyping • Catch basin cleaning • Street sweeping
BE 31	Pet waste, Sediment	• Pet waste management and education • Catch basin cleaning • Street Sweeping
BI 04	Wildlife, Pet waste, Sediment	• Further storm drain sampling at suggested locations within the drainage area for E.coli. and fecal coliform
BI 15	Wildlife, Pet waste, Sediment	• Pet waste management and education • Catch basin cleaning • Street Sweeping

Problem Solving and Implementation Activities: Best Management Practices for Bacteria Control

Sewer breaks and leaks, pet waste, sediment deposition, and wild life were identified as the primary sources of bacterial contamination at HAFB. In general, these sources were similar to the rest of the Shawsheen. HAFB implemented control measures and action to eliminate all sources except wildlife, a natural source with limited or no controls. The processes of bacteria elimination for the first three sources are discussed below.

As identified in the TMDL (DEP, 2002), leaks and breaks in the sanitary sewer lines as well as illicit connections are potential sources of raw sewage entering the Shawsheen River. Past water quality sampling conducted within the Shawsheen River Watershed (MRWC, 1996, 1997, 1998) discovered sewer line breaks and leaks throughout the watershed. A broken sewer main was discovered at the HAFB near the large outlets pipes that discharges into the Shawsheen River. In order to follow up on the reported sewer main break, as well as other possible breaks, HAFB, along with SWT, conducted an investigation of leaks and breaks in the entire sewer system. The investigation identified broken and crashed sewer pipes, and sanitary sewer cross connections to the storm sewer system. All of these potential sources were fixed by HAFB. The results of SWT's sampling revealed that the storm sewer system does not contain any leaks or breaks from the sanitary sewer system, as all dry weather fecal coliform samples meet the state's standard.

TMDL (DEP, 2002) identified pet waste as one of the potential sources of bacteria in Shawsheen. Pet waste is a significant source of fecal coliform to the urban environment. For example, a single gram of dog feces can contain 23 million fecal coliform bacteria (van der Wel, 1995). When improperly disposed, pet waste is washed into storm drains during a rain event and ends up in local streams and rivers. Once in the water body, the pet waste decays, using up oxygen and sometimes releasing ammonia in the process. Low oxygen levels and ammonia combined with warm temperatures create a lethal environment for aquatic life. Pet waste also contains nutrients that encourage weed and algae growth. HAFB implemented a management program that includes an education program targeted the residential area of HAFB and placing signs to discourage improper disposal of pet waste.

Another contributor of bacteria in urban areas is sediment. Numerous literatures suggest a relationship between sediment and bacteria (Van Donsel and Geldreich, 1971; Gerba and McLoed, 1976; Hood and Ness, 1982; Stephenson and Rychert, 1982; Sherer et al., 1992; and Davies et al., 1995). These papers stated that sediment provides a warm, dark and moist environment for bacteria to proliferate. Fecal coliform can survive and even multiply in sediments found in urban streams, ditches and drains. Also, there were documented cases of fecal coliform survival in catch basins and roadway curb sediments (Schueler, 1999a). The fecal coliform contaminated sediment enters a water body during a rain event. Within the water column, fecal coliform is shown to absorb to sediment particles and settle to the bottom (Schueler, 1999b). Sediment reduction BMPs implemented at HAFB included street sweeping and catch basin inspection and clean up. HAFB conducted street sweeping at least once a month using the dry vacuum sweeper. Street sweeping efforts were increased when needed. HAFB cleaned out catch basins on a yearly basis using vactor trucks (Fay, Spofford & Thorndike, Inc., 2001). However, HAFB conducted quarterly inspections of the catch basins for physical and operational conditions. If a catch basin were found to have excess sediment and/or debris, it would be cleaned out immediately. As a few of the downspouts from the roof drainage system directly discharge onto the grassy area, HAFB has installed splash pads at these discharge points to dissipate the energy from the impact of the flow so that soil erosion is minimized at these locations. With the lessons learned at control monitoring and implementation activities and subsequent improvements, a detailed implementation plan (Saravanapavan and Tasillo, 2003) was developed with specific recommendation for high bacteria concentered areas and general recommendation with following actions:

- Leak detection and elimination of damaged sewer pipes
- Pet waste education and outreach
- Illicit discharge detection and elimination
- Detection of failing septic system and elimination
- Increase the frequency of street sweeping and catch-basin clean up

Stakeholder Engagement in Addressing Aquatic Life Issue

Bacteria impairment and related issues have been felt and addressed by the state and local agencies (MADEP, 1990, 1996) before the formation of SWT. Therefore, when SWT was formed, one of the initial goals of SWT was to reduce bacteria loading in the Shawsheen River and its tributaries to meet the Massachusetts Water Quality Standards and remove the listed sections of the Shawsheen from the 303(d) list for bacteria impairments. To effectively address the bacteria impairment throughout the watershed, SWT deemed that a watershed wide approach was necessary to bring the stakeholders together to make appropriate decisions and actions related to this issue. SWT has launched several efforts, including data collection and analysis, TMDL development, planning restoration efforts, educating the local officials and decision makers, and integrating these understanding into practice in a set of steps, problem identification, problem recognition, implementation planning and policy adoption, and problem solving and implementing actions, as presented in Figure 4-20.

Based on the data collected in 1995, the state of Massachusetts placed the Shawsheen River in its 303(d) list of impaired waters under CWA (MADEP, 1999). As a result, the state was required to develop a TMDL, implement, and restore the Shawsheen from bacteria contamination. The 1995 monitoring results also have generated team's interest in further investigation, including a continuous monitoring during 1996 – 1999 (MRWC, 1999). It is important to note that SWT raised funds separately without using the annually allocated team's fund from the state government under MWI for the monitoring project (EOEA, 2003). The data collected gave the team a much more comprehensive view of water quality throughout the watershed. The data were also used to develop a Bacteria TMDL for the Shawsheen River (MADEP, 2002). As previously mentioned, TMDL sets a pollutant cap or ceiling that a water body can receive while still meeting the water quality standards. The Shawsheen TMDL was set so that the river and tributaries should approximately reduce the bacteria contamination by 90% (MADEP, 2002) to meet the state's water quality standard. Although the team was motivated to eliminate the bacteria contamination, there was no clear direction or studies to guide the team in controlling bacteria sources in urban environment to meet the water quality standard. In order to assist the team, a scientific investigation (Saravanapavan and Tasillo, 2003) was conducted to understand the capability of bacteria control measures in meeting water quality standards. A few consistent dry weather contributions were also found to be potentially associated with sewer breaks/leaks. Catch basins or stormwater inlets (to collect storm water from streets) with high sediment deposition were found to contribute high bacteria load to the river. Residential areas with signs of pet activities were also found to contribute high bacteria load to the river. Another source commonly found was urban wild life such as geese. On the other hand, the controlled sites, with a successful sewer leak/break detection and elimination program, pet waste management and education program, and proper pollution prevention such as frequent street sweeping and catch basin clean up, were found to contribute no bacteria loading during dry weather flows. In addition, the wet weather bacterial loads from the controlled sites were also substantially lower at one or two magnitudes lower in order. As a result of this study, SWT adopted sewer leak/break detection and elimination, proper catch basin clean up and street sweeping, and pet waste management and education, all of which were adopted as the primary control actions to protect the Shawsheen River from bacteria contamination (EOEA, 2003).

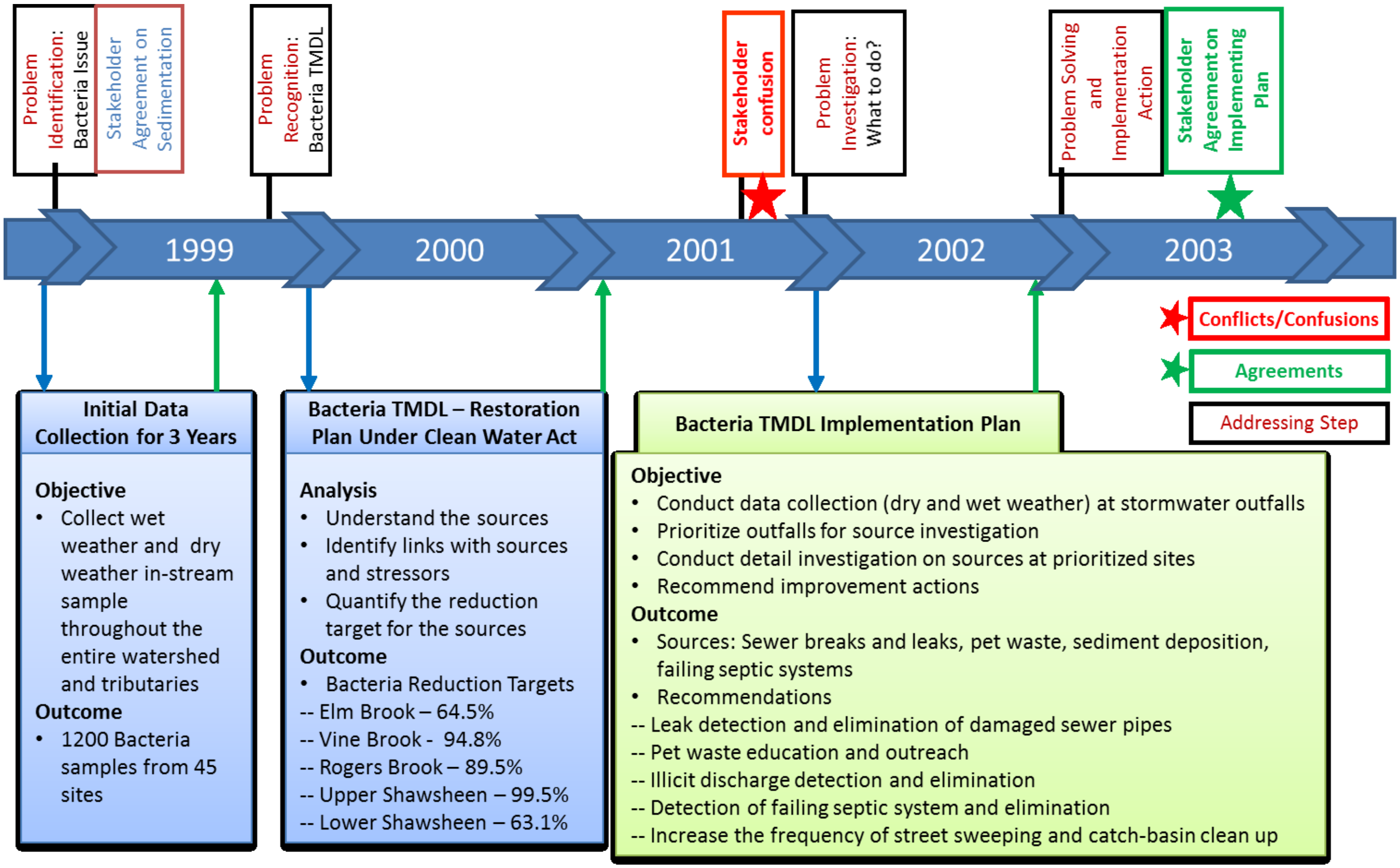

Figure 4-20. Addressing Bacteria Impairment Through Hybrid Planning: Steps, Decisions and Timeline

4.5 THE EFFECTIVENESS OF THE NEW MANAGEMENT FRAMEWORK

In Chapter 3, the new management framework was developed as a hybrid institutional model to overcome the weaknesses in both top-down and bottom-up approaches, while retaining and integrating their strengths, and to effectively address the urbanization impacts. The urbanization exerts negative multidisciplinary impacts on the integrity of natural watershed conditions and often require local inputs, as many of these are site specific and require consistent local monitoring along with appropriate policies and regulations from conventional governance. After detailed investigation of organizational characteristics (Section 4.3) of the framework and how the function (Section 4.4) of addressing the issues related to land use change and urbanization were addressed in previous sections, it is important to understand how these characteristics were effective in meeting its goals relative to the characteristics of a conventional approach (without the new management framework). Organizational and functional characteristics of the framework at Shawsheen, how the issues were addressed through it, and the overall effectiveness in the watershed are analyzed and presented in this section.

4.5.1 Organizational Effectiveness

In the early 1970's a watershed organization, the Shawsheen River Watershed Association, was formed by concerned citizens to address fears that contaminants were flowing off the Hanscom Air Force Base property into the mid-basin mainstem part of the river and threatening the wildlife habitat that resided in the area. When contaminants were contained by the mid-1970's, interest waned and the organization disbanded. Soon after, other citizen interests were resurrected in the mid- to late-1980's to address river pollution (EOEA, 2003a). In 1990, the recreational users, especially groups organizing canoeing and kayaking, discovered the excess amount of debris that challenged the navigation through the river and formed the Shawsheen Watershed Environmental Action Team (SWEAT). SWEAT organized river cleanup programs to physically remove the human borne debris on the sides and bottom of the river, from Bedford to Lawrence. Since 1990, this group has removed thousands of tires and hundreds of grocery store shopping carts from the river (EOEA, 2003a). Other than these isolated effort, prior to formation of SWT, no governmental or non-governmental organization existed to specifically address the protection of the Shawsheen watershed at the same forum. Federal, state, and local agencies independently performed some activities of watershed protections within their mandates and boundaries. A non-governmental organization, MRWC, was the only private organization that existed to address the watershed protection within watershed boundaries. However, the focus of MRWC was the entire Merrimack Basin of 12,976 km^2. The Shawsheen (200 km^2) is one of the seventeen watersheds in the Merrimack River Basin. Therefore, no coordinated effort, commitments from organizations including governmental and non-governmental, and permanent establishments existed to conduct watershed management to protect and restore the Shawsheen River. It is important to note that SWT was the first platform formed to conduct the watershed management by integrating all stakeholders including governmental and non-governmental organizations in the Shawsheen River Watershed. It is also important to notice that a new non-governmental organization, Shawsheen River Watershed Association (SRWA), was formed through the organization, function, and facilitation of SWT's watershed management processes. There was no connection between SRWA formed and chartered as non-profit organization in 2001 and the one with similar name operated between 1970s and 1980s. Although the government agencies or non-government agencies had meetings and forums to address their objectives independently, the quarterly meetings of SWT was the first forum to facilitate all stakeholders under a single umbrella. It helped to exchange ideas and knowledge that otherwise would not have been available to the stakeholders. Another important characteristic that existed in SWT and would not have existed in the conventional approach was sharing the responsibility. Through comprehensive planning and coordinated actions, SWT demonstrated that the same resources and knowledge could be effectively used when put together and shared rather than isolated and used on an individual basis. Table 4-14 summarizes and compares the major characteristics of the new management framework.

Table 4-14. Comparison of organizational and functional characteristics of the new framework.

CHARAECTERISTICS	WITH NEW FRAMEWORK	WITHOUT NEW FRAMEWORK
Common platform	• SWT coordinated all governmental and non-governmental activities	• No permanent establishment • Issues could be addressed independently by different agencies and organizations
Partnership	• Formed SRWA, a non-governmental organization • Involvement of government agencies, non-governmental organizations, private companies, and private citizens	• Governmental agencies require inviting the public for some activities for tokenistic participation. • No integration or coordinated involvement of governmental and non-governmental organizations.
Facilitation	• Quarterly Team Meetings • Mechanism to integrate local knowledge with governmental policies and regulations	• Independent facilitation primarily by government agencies • No mechanism to integrate local knowledge

4.5.2 Functional Effectiveness

Section 4.4 presented a detailed investigation on how watershed issues were addressed by SWT. More importantly, it was analyzed how 3C approach of stakeholders helped in addressing every step of the processes of water management and in moving one from the other. Overall observation on how these issues were addressed by SWT revealed that it was substantially different from addressing these issues through a conventional approach.

Among the hydrological issues, flooding is the only issue that would have been independently addressed by local municipalities and MA Department of Environmental Management (MA DEM) and Emergency Management Agencies. Prior to formation of SWT, there were significant tensions among these municipalities on who contributes the most in flooding issue. Also, the municipalities would have focused only on traditional hydraulic solutions of expanding culverts and bridges, raising the roadways, enlarging the conveyance structures, and building flood control structures. As noted in Section 4.2, these solutions might have shifted the problem from one place to another without solving the fundamental imbalances in the watershed due to urbanization. In the meantime, a well-coordinated effort by SWT resulted in implementing a comprehensive solution (Table 4-15) to hydrological issues. More importantly, a conflict of opinion on low flow and contribution of flooding resulted in scientific studies and education programs that brought not only the resolution to the conflict but also detailed implementation plan for Hanscom sub-watershed and no-net runoff policy for new and redevelopments.

Ecological issues, especially those related to aquatic life and habitat degradations, were generally addressed by statewide efforts from state agencies, MA Department of Environmental Protection (MA DEP), MA Department of Fish and Wildlife. However, it was not a priority issue of government agencies. At maximum, it could have been listed as "impaired." However, it was an issue brought into SWT by recreational local users and river stewards. Due to the least priority on government programs, SWT had limited funding to pursue this issue. In addition, the limited data and information availability and the technical complexity of the issue, it was somewhat of a challenging undertaking for SWT. As a result, SWT collected the funding separately to address this issue (Table 4-15), conducted a detailed investigation on the sources from the expertise from MRWC, US EPA, and Limno Tech, Inc., introduced an innovative approach to develop TMDL and acquired needed support and approvals from both governmental and non-governmental groups, developed TMDL, and coordinated the implementation of control measures to eliminate and minimize the ecological issue. This innovative approach was born due to a confusion among stakeholders after a failed attempt to develop a sediment TMDL. An innovative TMDL would not have happened without SWT, especially without addressing the flooding and low flow issue at the same time with all stakeholders involved. Also, the endorsement of the hydrological approach by TAC with well-known experts in the area paved the way for smoothing the review processes of the government.

Biological issues had been reported in the Shawsheen since 1960s (EOEA, 2003b) well before the formation of SWT. All the activities were performed by MA DEP, primarily to address the point source discharges and septic system failures based on the environmental complaints received from residents and other organizations. Due to the increased complaints on bacteria impairment, MA DEP conducted bacteria monitoring in 1989 and 1995 and listed the entire Shawsheen as "impaired." As presented in Section 4.2.3, there were no coordinated efforts to understand and isolate the sources and causes of the bacteria impairment before the formation of SWT. SWT sponsored a comprehensive data collection in 1996, 1997, and 1999 and it resulted in developing the first bacterial TMDL developed by a third party other than MA DEP in the Commonwealth of Massachusetts. In addition, SWT coordinated a detailed source investigation of bacteria by integrating state funding with additional funding raised through non-governmental members. If MA DEP were developing the TMDL, it would have been limited to the data collected in 1989 and 1995 and the investigations composed of complaints received from citizens. Also, there would not have been a detailed TMDL Implementation Plan (Saravanapavan and Tasillo, 2003a, 2003b) if the bacteria issue were addressed by MA DEP through its regular watershed management programs. This implementation plan was a result of another confusion at SWT on how to meet the targets set in bacteria TMDL. Only the new management framework made it possible to address these issues efficiently and effectively, through a collaborative effort by both government agencies and NGOs. Table 4-15 summarizes how hydrological, ecological, and bacterial issues were addressed in the Shawsheen compared to the typical top-down governmental programs.

Table 4-15. Comparison of addressing watershed issues by the new framework

ISSUES	WITH NEW FRAMEWORK	WITHOUT NEW FRAMEWORK
Hydrological	• Flooding issue was addressed by a coordinated effort of state and local agencies and non-governmental organizations. • Flooding and baseflow controls were addressed simultaneously using watershed based solutions. • Common understanding and agreement on the sources of flooding • Local policy for no net increase in runoff • Watershedwide education and outreach program • Detailed investigations and targeted planning for high priority areas with external funding • Watershedwide planning tool to understand the impact on baseflow	• Flooding issues would be addressed by local municipalities and MA DEM through isolated efforts. • Disagreement on the sources and contributors of flooding problem. • Baseflow deficit would not be considered as a priority issue
Ecological	• Coordinated investigation of aquatic life impairment and all associated stressors • Third party development of TMDL involving all stakeholders with external funding • An innovative approach to address all stressors through TMDL • Targeted implementation planning and actions with external funding	• Statewide assessments by DEP

Biological	• Coordinated multi-year monitoring by MA DEP (1989, 1995, and 2002) and by MRWC (1996, 1997, and 1998) • First third party TMDL in the state of Massachusetts coordinated through SWT • Comprehensive point and non-point source assessments • Detailed targeted monitoring to understand and isolate dry and wet weather sources • Pilot implementation to investigate the effectiveness of bacteria control measures	• MA DEP monitoring (1989, 1995, and 2002) • Targeted point source control through existing top-down discharge regulations • Targeted septic system control through Title V regulations

4.5.3 Institutional Effectiveness

As reported earlier in this chapter, urban land uses in Shawsheen approximately doubled between 1930s and 1990s and the most striking increase in development occurred between 1950s and 1970s. Although the impact of these changes had begun just after the development, it took longer to reach a level of impacting the day to day life of people living in the watershed. The lack of attention in part is associated with the natural ecosystem's ability to absorb these impacts to some extent and the non-existence of an institutional set up to appropriately address these issues. As a result, the cumulative impacts over a long time brought some chronic conditions to the natural ecosystem at Shawsheen. Until the introduction of the federally mandated Clean Water Act in 1972, the only mechanism of addressing the issues was "citizen complaints." Most of the complaints were related to physical observations and nuisance to day to day activities, such as flooding, bad smell, bad color, itch and rash when contacting with water, etc. The Clean Water Act strengthens federal and state environmental agencies and programs to address these impacts. Similar to experiences learned all over the world, the agencies were successful in controlling point-source related impacts from industrial activities and treatment activities that were large contributors of water quality impacts. In Shawsheen, MA DEP and US EPA were successful in permitting and enforcing point discharges in late 70s and 80s. Also, it helped the agencies to address citizen complaints through a systematic institutional framework. However, the agency activities and authorities failed to address two major issues, namely consistent flooding and non-point source pollution. These two issues were very evident in the Shawsheen (EOEA 2003a) and throughout the urban and semi-urban watersheds in the state of Massachusetts in 80s and early 90s.

Flooding is one of the issues that have been traditionally dealt by emergency management or natural disaster mitigation agencies under federal and state laws. In general, the governor of the state or the president of the United States has to declare emergency for these agencies to act. Although the floods that occurred in the Shawsheen in 80s and 90s resulted in interruption to livelihoods and property damages, they were not severe enough to get the attention from federal and state emergency laws. As a result, the responsibility of addressing the flooding issue fell into the isolated and individual efforts of the municipalities. The local communities brought local regulations to require control measures to avoid the impact of large storms, especially peak controls, for future development. It is important to note the complexity in addressing the flooding issues in Shawsheen that the 200 km^2 of Shawsheen watershed are located within the boundaries of 12 municipalities. As reported in Section 4.2, the communities have been frustrated by continued flooding problems even after they had spent substantial money in traditional flood control activities. This frustration was mainly attributed to the non-existence of an institutional mechanism to understand and address the flooding as a watershed issue rather than a municipal issue. Also, it is attributed to the lack of understanding in the source and causes of flooding issues as well as the gap in policies and decision making in addressing these issues. In a way, the flooding situation in Shawsheen helped to strengthen the 3C approach of SWT in late 90s. The activities of SWT not only resulted in implementing watershed flood control measure to mimic the pre-development water balance, but also helped create governing policies such as "no net increase in runoff" from all future development.

Due to the links among non-point source pollution issue, hydrology, land use and human activities in the watershed, US EPA promoted watershed approach in addressing non-point sources pollution issue through its National Pollution Discharge Elimination System (NPDES) stormwater program since 1990s. Except for the City of Lawrence, where a small portion of the Shawsheen is located, the rest of the municipalities in the Shawsheen were not included in the Phase I of implementing NPDES Municipal Separate Stormwater Sewer System (MS4) permit. Phase I permits generally have specific targets in pollutant control and associated programs. The rest of the eleven municipalities were included in the Phase II MS4 permit issued in 2000. Under this permit, the municipalities are set to control the stormwater pollution to "maximum extent practicable (MEP)" using available technology. MEP fails to define a numeric target or set a standard to meet.

Therefore, it primarily relied on voluntary actions of the local municipalities to minimize stormwater pollution.

Although TMDL development and approvals are mandated by the federal Clean Water Act to address water quality impairment issues, there were no regulatory or institutional mechanisms to implement the control and restoration actions identified in TMDLs to meet water quality standards. Even the developed TMDL lacked in detailed implementation plans that were later done by SWT through its own voluntary effort. However, the NPDES permit requirements generally address some of the issues and activities to minimize the water quality impacts from stormwater within the municipal boundaries. As an effective watershed management platform, SWT brought all the players together, directed the resources very effectively to understand the issues, prioritized the attention required, prioritized the resources to be utilized, shared the science, technology, and local knowledge to address the issues, and developed comprehensive watershed plans to implement necessary action by sharing the responsibility among all stakeholders. Table 4-16 summarizes the institutional effectiveness through regulations and decision makings over the past few decades to understand the relative merits of the characteristics of the new management framework in addressing the issues associated with urbanization. Text indicated in bold and italic are the overall enhancement to the watershed management from implementing the characteristics of the new management framework in Shawsheen.

Table 4-16. Institutional effectiveness of the new framework in addressing urbanization issues. The text in *bold italic* indicates the contribution through the new framework.

Decade	Issues	Major Driver to Address the Issue	Institutional Effectiveness
1960s	• Water Quality	• Citizen complaints	• Limited follow up actions by MA DEP
	• Flooding	• None	• None
1970s	• Water Quality	• Clean Water Act of 1972 • Citizen complaints	• Permitted point source pollution control by US EPA and MA DEP • Follow up actions by MA DEP
	• Flooding	• None	• None
1980s	• Water Quality	• Clean Water Act of 1972 • Citizen complaints	• Permitted point source pollution control by US EPA and MA DEP • Follow up actions by MA DEP
	• Flooding	• Nuisance Flooding • Property Damages	• Isolated actions within municipal boundaries
1990s	• Water Quality	• Clean Water Act of 1972 • Citizen complaints • Municipal NPDES Phase I for stormwater control • TMDL Regulations under Clean Water Act • ***Shawsheen Watershed Team***	• Permitted point source pollution control by US EPA and MA DEP ***(Coordinated by SWT)*** • Follow up actions by MA DEP ***(Coordinated by SWT)*** • ***Watershedwide Monitoring*** • ***Targeted Monitoring and Assessment at Hanscom***
	• Hydrology ***(Flooding and low flow)***	• Nuisance Flooding • Property Damages • Municipal NPDES Phase I for stormwater control • ***Severe Draught in 1999*** • ***Shawsheen Watershed Team***	• Isolated actions, traditional hydraulic solutions, within municipal boundaries ***(Coordinated by SWT)*** • Peak control requirements for new development by local municipalities • ***Recognizing watershed solutions***
2000s	• Water Quality	• Clean Water Act of 1972 • Citizen complaints	• Permitted point source pollution control by US EPA and MA DEP ***(Coordinated by SWT)***

		• Municipal NPDES Phase I and Phase II for stormwater control • TMDL Regulations under Clean Water Act • ***Shawsheen Watershed Team***	• Isolated NPDES MS4 Phase II compliance activities ***(Coordinated by SWT)*** • ***TMDL development for bacteria and aquatic life impairment*** • ***Detailed implementation plans to meet bacteria and aquatic life TMDL goals***
	• Hydrology ***(Flooding and low flow)***	• Nuisance Flooding • Property Damages • Municipal NPDES Phase I and Phase II for stormwater control • ***Shawsheen Watershed Team***	• ***Water balance study to understand the relative contribution of sub-watersheds*** • Isolated actions, traditional hydraulic solutions, within municipal boundaries ***(Coordinated by SWT)*** • Peak control requirements for new development by local municipalities • ***No net-runoff policy in approving all new development project*** • ***Detailed implementation plan and actions to flow control and to meet aquatic life TMDL goals***

4.5.4 Environmental Water Quality Effectiveness

In summary, the new management framework provided an institutional platform that integrates all parties in addressing the adverse hydrological, ecological, and biological impacts from urbanization. Through the effective 3C approach, each aspect of the interconnected issues was managed with satisfactory results. Regardless of great success in institutional effectiveness, the ultimate success will be determined by success of environmental water quality. The implementations actions identified through this planning effort are technically intended to reverse the cumulative impacts from over 50 years on the river system. Although it will take a long time for the river system to respond to these positive changes, the data collected after implementing the actions revealed encouraging outcomes. The Bacteria issue was the only issue that had the implementation actions carried out throughout the Shawsheen watershed. The data collected by

MA DEP in 2002 and 2010 (Table 4-17 and Figure 4-21) revealed that bacteria counts for three sites, one each represents upper, middle, and lower Shawsheen River respectively, were reduced by more than a magnitude. The reduction is attributed to the bacteria control measures implemented throughout the watershed as per the implementation developed by SWT under the new management framework.

Table 4-17. Geometric mean Fecal Coliform Counts at Shawsheen in 2002 and 2010.

Site	2002 (MA DEP, 2005)	2010 (MA DEP, 2012)
MA09A-149: Upper Shawsheen	13,834	490
MA09A-176: Middle Shawsheen	24,000	3,335
MA09A-137: Lower Shawsheen	5,414	204

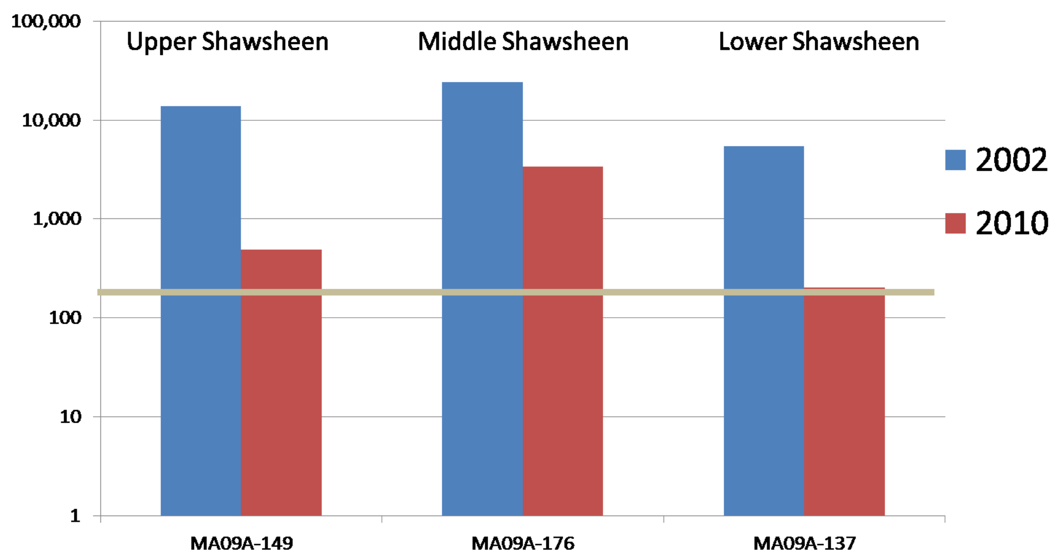

Figure 4-21. Sampled Fecal Coliform counts and geometric mean at the Upper, Middle and Lower Shawsheen Sites (MA DEP, 2005, 2012). Massachusetts standard for class "B" water, Shawsheen, is 200 counts/100 ml.

More importantly, the implementation action throughout the watershed by all involved stakeholders resulted in improvement in bacteria counts (MADEP, 2012) and the recognition through regulation by removing a few segments from the impaired list after a series of data collection at many sites in Shawsheen. Approximately 8 km of river segments, including a portion of Upper Shawsheen main stem, Content Brook, Meadow Brook, and Fosters Brook were removed in the 2014 303 (d) list compared to 1998 303 (d) list.

Implementations of the new management framework at the Shawsheen River Watershed highlighted the benefits from an interdisciplinary management approach, in which scientific analysis played a critical role in implementing the framework, specifically to sustain the three key components, common platform, partnership, and facilitation through 3C approach. This is particularly applicable to the Shawsheen River Watershed and many watersheds in developing countries, where the monitored biological and ecological data might be limited. In order to better exemplify how the new framework operates in interdisciplinary settings, and to illustrate the critical role that science plays to meet the comprehensive watershed management objectives, the framework applications at Hanscom sub-watershed are analyzed in detail in Chapter 5. The environmental quality effectiveness at Hanscom is also reported in this chapter.

5.0 INTERDISCIPLINARY PLANNING APPROACH AT HANSCOM SUBWATERSHED

Through successful implementations at the Shawsheen River Watershed, the new management framework has proved to be an effective tool in assisting the management of watersheds experiencing urbanization. The implementations have also led to advancement in science with regard to innovative interdisciplinary approaches for comprehensive watershed management. This Chapter uses the Hanscom sub-watershed as an example to fully illustrate both the innovative "hydrology as surrogate" concept and implementations of the new framework. Part of the findings presented in this Chapter has been published (Saravanapavan et al., 2014).

5.1 THE NEED FOR AN INNOVATIVE APPROACH

Natural river flow conditions around the world have been negatively impacted as the trend of urban sprawl continues to accelerate (Chen and Wu, 1987; Sparks, 1992; Dynesius and Nilsson, 1994; Walker et al., 1995). Changes in flow conditions directly influence river biota, especially the habitat and aquatic life (Ward and Stanford, 1979; Petts, 1984; Calow and Petts, 1992). For example, organisms that are sensitive to flow velocity, including periphyton, phytoplankton, macrophytes, macroinvertebrates, young fish and deposited eggs, are easily displaced as a result of increased frequency or duration of high flow levels (Moog, 1993; Allan, 1995). Channelization and dredging, as well as riparian vegetation elimination all modify the habitat (OEPA, 2012). At the same time, pollutants discharged into rivers and other receiving water bodies also cause adverse biological effects: infection of organisms by bacteria and viruses, increased biological oxygen demand (BOD) and lower dissolved oxygen (DO), death from chronic toxicity exposure and alteration to natural habitat cycles and breeding, etc. (Zoppou, 2001; Whitehead et al. 2006). In fact, habitat alteration and impaired biota have been the leading causes of impairment in assessed United States rivers and streams for many consecutive years, regardless of designated uses (USEPA, 2007).

In the United States, the total maximum daily load (TMDL) program has been established by the Clean Water Act (CWA) to address water quality issues in the nation's waters. The development of TMDL for a specific water body involves identifying the pollutant/stressor causing the water quality impairment, estimating the amount of pollutant that the water body can assimilate, calculating pollutant loadings from various sources, determining allowable pollutant loads based on analysis of pollution in the water body, and finally allocating pollutant loads with a margin of safety (MOS). The TMDLs are usually developed using either or both of the U.S. Environmental Protection Agency (USEPA) approved methods: load duration curves (LDCs) and/or water quality models (USEPA, 2007). While load duration curves are often applied to small watersheds where flow is the primary mechanism in pollutant loading, water quality models are more appropriate in analyzing larger, more complex watersheds where watershed-scale pollutant transport models are needed (Sakura-Lemessy, 2009). Since the inception of the TMDL program in the 1970s, a total of 39,478 non-point source TMDLs has been developed for various pollutants (e.g. pathogens, sediment, nutrients, heavy metals, temperature, bacteria, etc.) around the U.S. in addressing various water quality issues (USEPA, 2011).

Despite wide-spread implementations of the TMDL program, limited numbers of TMDLs were developed to directly address the habitat and aquatic life impairments. This is mainly due to the fact that evaluations of interrelationships between flow phenomena and biotic responses can be time consuming due to long-term monitoring and analysis needs, and this is further complicated by the fact that habitat and aquatic life impairments are often caused by multiple stressors. The stressors could vary from known and unknown pollutants to storm water runoff, hydrologic modifications, riparian corridor encroachment, and to channel alteration (NRC, 1992; Richter, 1997). The determination of exact role and relative significance of each pollutant/stressor in contributing to the impairment could easily exceed the technical and fiscal resources of many communities. As practical TMDL implementation plans require reduction targets for specific stressor(s), the lack of definitive relationship between habitat and aquatic life impairments and corresponding stressor(s) limits the development of traditional TMDLs for water quality protection (OEPA, 2012).

A comprehensive review of water quality cannot be achieved without accounting for changes in hydrological regimes. Although many are not directly initiated through TMDL efforts, a growing body of scientific literature has endorsed the “natural flow paradigm” for meeting ecological management targets in rivers and streams (Richter et al., 1997; Poff et al., 1997; Bunn and Arthington, 2002; Postel and Richter, 2003; Arthington et al., 2006; Richter, 2009). The objective for the approach is to restore native aquatic biodiversity and ecosystem integrity through maintaining or restoring some semblance of natural flow variability (Richter et al., 1996; Stanford et al., 1996; Richter et al., 2011). The key underlying argument for the approach is that hydrological variations play a major part in structuring the biotic diversity within ecosystems, mainly through the controlling of key habitat conditions within the river channel, the floodplain, and hyporheic (stream-influenced groundwater) zones (Poff and Ward, 1989; Arthington and Pusey, 1994; Townsend and Hildrew, 1994; Stanford et al., 1996). Moreover, the exchanges of organisms, particulate matter, energy, and dissolved substances along the upstream-downstream, river-floodplain, river-hyporheic, and temporal dimensions of riverine ecosystems are substantially mediated by flow conditions including stream flow, floodplain inundation, alluvial groundwater movement, as well as water table fluctuations (Ward and Stanford, 1983, 1995; Ward 1989; Sparks et al., 1990; Walker et al., 1995; Richter et al. 1997).

An innovative approach in which the natural hydrology is regarded as surrogate for developing TMDLs for habitat and aquatic life impairments caused by unspecified sources is introduced in this study. The approach builds on existing body of knowledge regarding flow regime and ecological integrity and incorporates the attainment watershed approach during the TMDL development. With the specific goal of developing TMDLs for habitat and aquatic life impairments caused by multiple stressors, the innovative approach is illustrated in the Shawsheen watershed in Massachusetts.

5.2 USING HYDROLOGY AS SURROGATE

Historical studies linking hydrological parameters and stream ecological integrity provide references for choosing surrogates for habitat and aquatic life impairment assessments. Arthington et al. (1991) evaluated four attributes of natural flow regime in drawing flow recommendations in Australia, and the attributes include low flows, first major wet-season flood, medium sized floods, and very large floods. The flow target for maintaining natural flow regime was set as the lowest flow that occurred often (e.g. estimated as a specified percentile exceedance flow for each month). Richter et al. (1997) proposed the Range of Variability Approach (RVA) to help conserve native aquatic biodiversity and protect natural ecosystem functions in rivers and streams. The approach recognizes the fact that human-induced flow alterations can both deplete and unnaturally augment natural flows to the detriment of ecological health. As a result, the approach subsequently establishes the band of allowable alterations called “sustainable boundaries” around natural flow conditions as a means of expressing environmental flow needs. The extent to which the hydrologic variability, as well as the associated characteristics of timing, frequency, duration, and rates of change, helps sustain aquatic ecosystems was analyzed and incorporated in the approach.

5.2.1 Flow Duration Curve

In urban streams where multiple stressors contribute to habitat and aquatic life impairments, the identification and prioritization of individual stressors pose substantial technical and fiscal challenges to local communities. In the meantime, the natural flow regime has long been recognized as the cornerstone for determining ecosystem flow requirements, and thus it should always be mimicked for restoring activities (Poff et al. 1997, Tharme and King 1998).

While numerous hydrological parameters are available for describing flow variability, the selected hydrology surrogate for water quality TMDL development has to retain strong ecological and geomorphological associations on one hand, and to be simple enough for practical implementation on the other hand (Growns and Marsh, 2000). The flow duration curve (FDC) is one of the most commonly used ways to display the distribution of stream flows under either natural or regulated conditions (Gordon et al. 1992). A sample flow duration curve is illustrated in Figure 5-1. As shown in the figure, the high and low ends of the curve give indications of the flooding and base flow conditions in the stream. The shapes of the curves are signatures of flow characteristics of a stream for comparisons within or between catchments. The curve can also serve as the basis for generating duration curves of sediment, turbidity, water hardness, or other water quality characteristics, provided that a relationship is established between stream flow and the characteristic of interest (Gordon et al., 1992). That is, the FDC for a stream provides the potential linkage between measurable hydrologic parameters (e.g. flow rates at different exceedance levels) and corresponding water quality situations which are directly connected to attainment of designated uses.

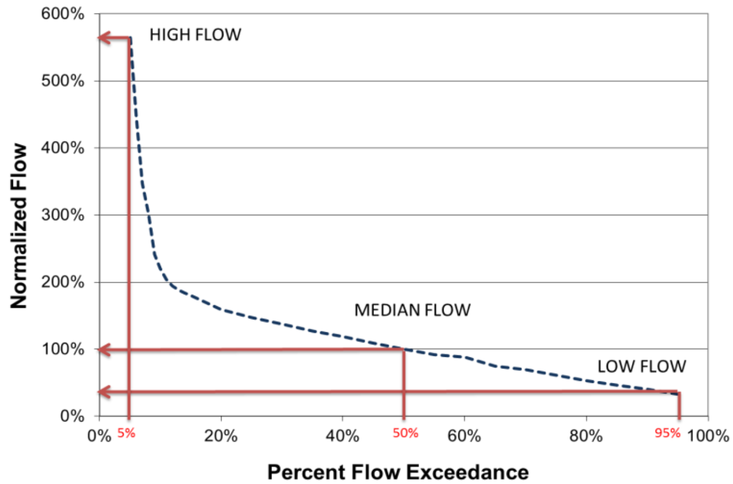

Figure 5-1. Sample Flow Duration Curve (FDC).

5.2.2 Attainment Watershed Approach

The attainment watershed approach is a common approach for TMDL development (Brown, 2013). The approach first identifies watersheds with similar characteristics as the watershed of interest (with impairment), but at the same time, attain water quality standards. Flow conditions in the "attainment watersheds" then set the baseline or reference for TMDL control targets. This approach is useful for situations where the basis of the impairment or the pollutant of concern is directly related to the flows generated in the watershed of interest. The major assumption of the approach is that the impaired water body would meet the water quality standards or designated use if the conditions in the impaired watershed are brought to levels similar to those in the attainment watershed.

While implementing the attainment watershed approach, it is critically important that the selected attainment watershed have similar hydrologic characteristics (e.g. land use, soils, slope, climate, etc.) as the watershed of interest. When the selected attainment watershed(s) has drastically different characteristics from the watershed of interest, the analysis may result in misleading conclusions (Brown, 2013).

5.2.3 Innovative TMDL Development Approach

A surrogate TMDL development approach was proposed based on the reviews of literature. The surrogate, which is the flow duration curve, is capable of correlating a measure of biological response in the water body to pollutants and stressors, as well as to designated water quality standards.

In the proposed TMDL development approach, attainment watersheds with characteristics that are similar to those of the study watershed were first identified. Flow duration curves were then generated for both the attainment watershed and the impaired watershed, and the surrogate TMDL for the impaired watershed can be set as high, medium, and low flow rates at different exceedance levels (e.g. 5%, 50%, and 95%). The FDCs can be normalized by watershed area in order to facilitate cross-comparisons.

The surrogate TMDL based on the FDC is expected to provide assurance for water quality attainment for urban streams under multiple stressors in that the curves are closely related to water quality impairments in the streams. As high flow events increase in the impaired watershed, the potential for higher pollutant loadings, more severe scouring and stream bank erosion, as well as displacement of biota all increase. On the other hand, the reduction in stream base flow may also lead to loss of habitat for low flow conditions. This choice of FDC is further validated by the fact that the curves incorporate the full spectrum of flow conditions that occur over a long period of time and consist of seasonal variations.

For impaired and attainment watersheds that have limited hydrologic data to develop the surrogate TMDL, a calibrated rainfall-runoff watershed model is often needed to generate synthetic FDCs for both watersheds. The surrogate TMDLs can then be developed for the impaired watershed by indicating the percentage of reductions or increases relative to selected locations on the FDCs of the attainment watershed.

5.3 INTEGRATING SCIENCE INTO DECISION MAKING

The proposed new planning approach is integrated into the decision making under the new framework as indicated in Figure 5-2. SWT gave the common platform and the appropriate partnership to conduct effective watershed management in addressing the aquatic life impairment and also provided the appropriate facilitation mechanism through cyclic sets of steps with the continuous stakeholder updates through quarterly meetings. At the beginning of the study, it was not considered an important issue to be addressed by SWT members. Except environmental stewards and community members, others were reluctant to allocate the team resources for this issue. The science, targeted data collection on habitat and macroinvertebrates, helped with the recognition of the issue and made the team to accept the issue as one of the priority issues. Later SWT began the TMDL process as "Sediment TMDL" and faced a roadblock that the identification of sources of sediments and linking them to the impairment was impossible. As a result, the science, interdisciplinary approach, guided SWT to develop TMDL and a restoration plan that utilizes stormwater management and controls as targets, and to identify BMP. The following section presents the details on how science is integrated into achieving the results through the new management framework.

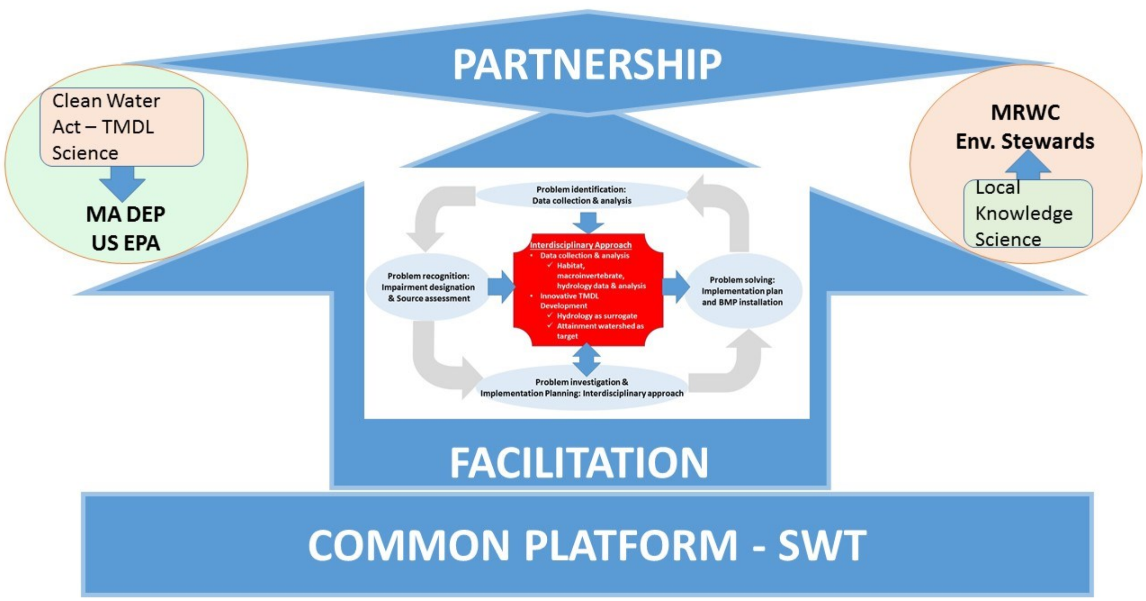

Figure 5-2. Integration of the Innovative Approach in the New Framework in Aquatic Life and Habitat Issue at Hanscom.

5.3.1 Integration of Science in the Framework

The integration of science began when SWT documented habitat and aquatic life impairments in the Shawsheen headwaters based on past data collection and it resulted in placing these affected waters on the list of the State's impaired waterbodies, under the Federal Clean Water Act. At the beginning of the study, it was not considered an important issue to be addressed by SWT members. Except community members and environmental stewards, others were reluctant to allocate the team resources for this issue. A comprehensive data collection (MRWC, 1999) by the SWT confirmed the existence of these impairments. This process helped with the recognition of the issue and made the team to accept the issue as one of the priority issues. The team decided that developing a TMDL was an appropriate avenue to address this issue. Although there was an agreement among members in addressing the issue, there were differences on the understanding and accepting of the sources. It resulted in a few discussions on how to address it through the TMDL process. For example, a few members felt that it was a water quality issue and others felt that it was a flow issue. Regulatory agencies accepted it as a water quality issue so as to address it through TMDL process. The initial attempt was proposed by MA DEP and US EPA to develop it as a TMDL for sediment. However, it was abandoned after SWT failed to identify specific sediment sources in the watershed. The confusion of the stakeholders on "what to do next?" under TMDL program paved the way for an innovative planning approach for developing TMDLs. The attempt was clearly deliberated at quarterly meetings through scientific analysis so that it was easy for a common understanding and agreement to look for an innovative approach. In order to bring together the diversified members, an interdisciplinary approach as a part of the new management framework, using hydrology as a surrogate to all known and unknown sources, was born. The approach was the first of its kind in the United States that introduced an attempt to address multiple urban stressors causing aquatic life impairment, especially in the context of TMDL development.

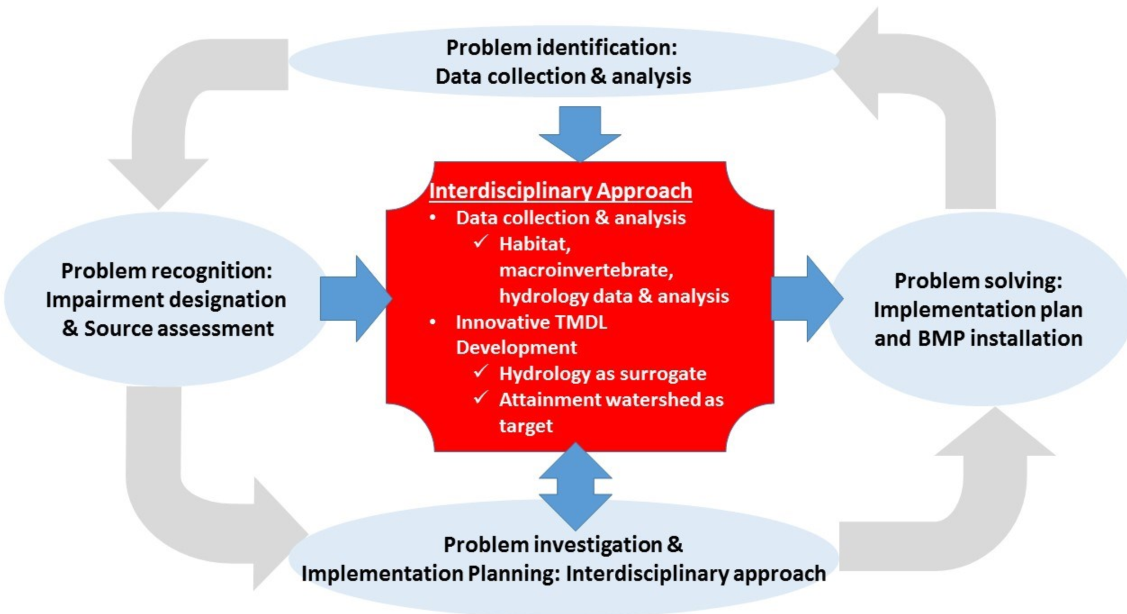

Figure 5-3. Integration of the Innovative Approach in the Decision-Making Process of Aquatic Life and Habitat Issue at Hanscom.

5.3.2 Implementation Plan

The attainment watershed for the Hanscom watershed was a separate headwater tributary within the Shawsheen watershed. The Elm Brook, with similar land cover, topography, and geology as the Hanscom watershed, bordered the Hanscom watershed to the west. The upper portion of the Elm Brook is dominated by wetlands, heavy vegetation and slow moving water, and the lower portion has higher levels of residential and commercial developments. Biological monitoring results indicated that the Elm Brook meets Massachusetts Water Quality Standards for aquatic life (MADEP, 2003).

The Generalized Watershed Loading Function (GWLF) model was created and calibrated (Saravanapavan, et al., 2000, 2004) to derive long-term flow conditions at the Hanscom and Elm Brook watersheds. The FDCs for the two watersheds are shown in Figure 5-3, in which the flows are expressed as the percentages to the median flow rate.

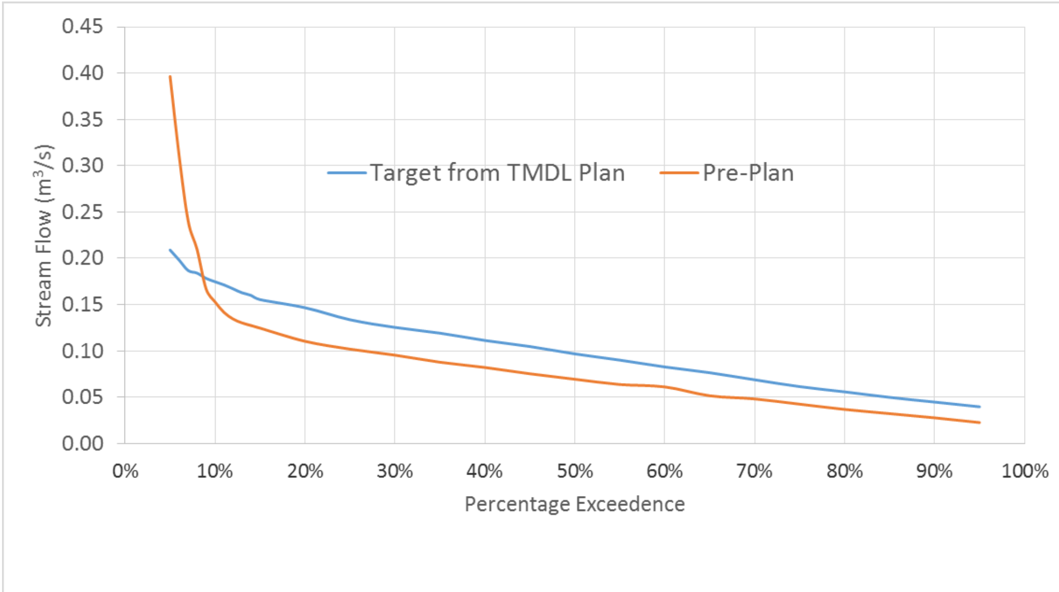

Figure 5-4. FDCs of Pre-TMDL (Orange Line) and the target as per TMDL (Blue Line) for Hanscom Watershed.

In the development of the high and low flow metrics for the TMDL development in the Hanscom watershed, the 5 percent exceedance flow (high flow) and 95 percent exceedance flow (base flow or low flow) were chosen. A comparison of the flow metrics between the impaired Hanscom watershed and the attainment Elm Brook watershed set the flow targets for meeting TMDL plan as presented in Table 5-1.

Table 5-1. Flow Metrics for the TMDL Plan at Hanscom.

Hydrology indicator	Pre-Plan	Target from Plan
95% exceedance flow (m^3/s) – Low Flow	0.022	0.040
50% exceedance flow (m^3/s) – Median Flow	0.069	0.097
5% exceedance flow (m^3/s) – High Flow	0.396	0.209

Simulation results indicated that the identified hydrological target would reduce the pollutant load (sediment, metals, etc.) associated with stormwater runoff around 47 percent, and pollutants were assumed to be transported from the watershed to the river by surface runoff (MADEP, 2003). The

Shawsheen watershed TMDL development served as pioneering examples to many other flow-based surrogate TMDLs around the country (OEPA, 2012).

In addition to filling the existing gap between urban streams with habitat and aquatic life impairments caused by multiple stressors and a practical and implementable TMDL, the surrogate TMDL bypasses the traditional “pollutant of concern” approach and addresses adverse water quality impacts directly. This is mainly due to the fact that loads of sediment and other pollutants are a function of the amount of stormwater runoff generated from a watershed. Additionally, the surrogate approach allows for the accounting of physical impacts to the stream channels caused by stormwater runoff. Such impacts, varying from sediment release from channel erosion to scouring from increased flows, are primary contributors to aquatic life impairments. As the surrogate TMDL sets targets for increasing low flow, aquatic lives dependent upon base flow are also addressed. Overall, the approach is in accord with the notion of sustainable water resources management, in which the maintenance of environmental flows capable of sustaining healthy river ecosystems should be viewed both as a goal and as a primary measure of success (Richter, 2009).

While the proposed FDC approach for TMDL development shares many similarities with the LDC approach, the two approaches are different from each other in terms of applicability. Similar to the LDC approach, the FDC approach assumes that strong correlation exists between habitat and aquatic life impairment and flow conditions (USEPA, 2007). Thus, both methods will not work when factors other than flow significantly affect the water quality conditions of a water body (Shen and Zhao, 2010). When being implemented, however, the FDC approach requires much less data than the LDC approach, which often involves extensive water quality data collection over a wide range of flow conditions. Such data are especially challenging to obtain for habitat and aquatic life impairment situations. More importantly, the FDC approach offers a unique opportunity for watersheds with impairments caused by multiple, unknown stressors to begin addressing water quality issues with reasonable confidence. This will be difficult through the LDC approach, which requires the identification of stressor(s) and the relative importance of stressor(s) to begin the analysis. In comparison, the FDC hydrology surrogate approach can bypass these prerequisites, and the analysis results can guide the implementation of practices such as imperviousness demolition, groundwater recharge, and green infrastructure, etc. Such practices are well tested for the improvement of watershed hydrologic conditions, which eventually leads to restoration of water quality.

The innovative surrogate approach does not attempt to replace traditional TMDL approaches, in which stressors are often clearly identified and limits for a particular pollutant are calculated and apportioned as an overall load among point and nonpoint sources. Instead, the approach presented here is specifically developed for impaired urban streams under multiple stressors, and more importantly, no single pollutant can be identified as the main stressor in these impairments. As a result, the TMDL targets following this approach are specified as changes in watershed runoff conditions at various flow exceedance levels, instead of the apportioned load reduction targets as obtained through traditional TMDLs. Whenever fiscally and technically possible, a continuous monitoring program should be included as an integral part of a water quality assessment scheme in the development of TMDLs, coupled with physically-based watershed modelling analyses. That is the traditional and reliable way to quantify the relative magnitude of different sources, their location in the watershed, their changes over time, as well as reactions to different management practices. As previously discussed, this relatively simple approach is not likely to succeed when the actual stressor(s) is (are) not related to stormwater runoff. The approach also has not been tested for situations involving significant anthropogenic water withdrawal and release activities which are prevalent in reservoir management for water distribution and in irrigation practices in rural watersheds.

In conclusion, the innovative approach of using hydrology as surrogate proves to be effective in managing watersheds that are faced with urbanization impacts but at the same time are bounded by limited data and technical capabilities. Instead of going through the traditional tedious and expensive processes of data collection, analysis, model development, and control measure assessment, this new approach provides a simple yet reliable alternative for effective watershed management. The power of the approach is fully utilized through the new management framework, in which the scientific findings from the new approach is best employed for informed decision making that involve all stakeholders.

5.4 EFFECTIVENESS ON ENVIORNMENTAL WATER QUALITY

An innovative approach to develop surrogate TMDLs for urban streams under multiple stressors has been introduced in this research. The approach, based on existing knowledge regarding flow variability and corresponding stream ecological integrity, uses flow duration curve as quantifiable and practical control targets. High, medium, and low flow values on the FDC were used to set the TMDL targets. In addition to filling the existing gap between urban streams with habitat and aquatic life impairments caused by multiple stressors and a practical and implementable TMDL, the surrogate TMDL bypasses the traditional "pollutant of concern" approach and addresses adverse water quality impacts directly. This is mainly due to the fact that loads of sediment and other pollutants are a function of the amount of stormwater runoff generated from a watershed. Additionally, the surrogate approach allows for the accounting of physical impacts to the stream channels caused by stormwater runoff. Such impacts, varying from sediment release from channel erosion to scouring from increased flows, are primary contributors to aquatic life impairments. As the surrogate TMDL sets targets for increasing low flow, aquatic lives dependent upon base flow are also addressed. Overall, the approach is in accord with the notion of sustainable water resources management, in which the maintenance of environmental flows capable of sustaining healthy river ecosystems should be viewed both as a goal and as a primary measure of success (Richter, 2009).

While claiming the merits for new innovative planning approach and receiving the approval and endorsement from US EPA and other state environmental agencies (Brown, 2013, OEPA, 2012), the ultimate success of the approach will be determined by not only meeting hydrological targets, but also showing the evidence of improved aquatic life. As previously mentioned, the impairment came from the cumulative land use activities over 50 years so that the actions reversing the impacts are also expected to takes place for many years. A field visit and stakeholder meeting was conducted in December 2013, almost after 10 years after developing the plan, to collect necessary data and information to document the effectiveness in environmental water quality. Table 5-2 gives the details of the participants of the filed visit.

Table 5-2. Attendees of field visit and stakeholder meeting to witness the implementation action at Hanscom sub-watershed on December 27-28, 2013.

Name	Affiliation
Prof. Eiji Yamaji	The University of Tokyo
Mr. Bill Dunn	Massachusetts Department of Environmental Protection
Mr. Mark Voorhees	United States Environmental Protection Agency
Mr. Don Morris	United States Air Force
Mr. Bob Rauseo	Shawsheen River Watershed Association
Mr. Tham Saravanapavan	Tetra Tech, Inc.

5.4.1 Implementation Actions on the Ground

As previously reported, the implementation actions began according to the implementation plan (Saravanapavan, 2002) as presented in Figure 5-5 again for easy reference. According to the Massachusetts state stormwater handbook, the implementation of all the three types of BMPs are subject to certain site constraints such as surface slope, wetland locations, soil conditions, and land use/land cover (Saravanapavan, 2002). The SWT performed a desktop analysis to identify potential sites for BMP implementation. The potential sites were then submitted to a quarterly meeting for review, in combination with verification results from field survey. Based on the field survey, SWT review, and USAF engineering unit inputs, the locations and types of the BMPs were finalized and were selected for design and construction (Figure 5-5).

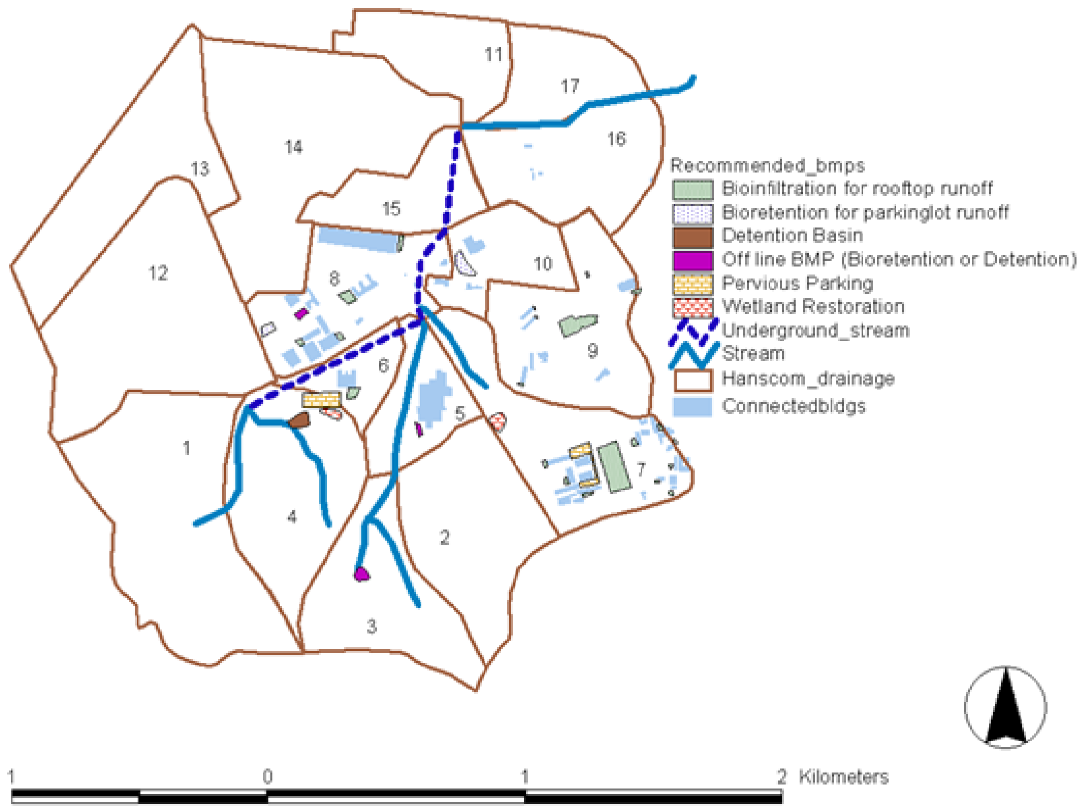

Figure 5-5. Final list of selected BMPs to be located at the Hanscom US Air Force Base to meet the goals of the Shawsheen headwater TMDL.

SWT has identified the following BMPs categories:

- Recharge/infiltration BMPs,
- Low impact development strategies, and
- Extended detention BMPs.

Recharge BMPs were designed to infiltrate collected stormwater into the ground. These BMPs include surface systems, such as retention basins, and underground systems, such as infiltration galleys and leaching catch basins. These systems are typically installed at the end of a stormwater collection system and operate by temporarily storing stormwater and allowing it to percolate into the ground. Siting of recharge BMPs is primarily dependent on two factors: soil hydraulic conductivity and groundwater elevations. Effective recharge systems must be located in soils with sufficient permeability to allow groundwater to recharge between storm events. A few pictures

(Figures 5-6, 5-7, 5-8, and 5-9) are presented below to demonstrate representative implementation action from different types of BMPs.

Figure 5-6. Infiltration BMP to capture and infiltration of runoff from parking lots (Picture provided by Mr. Don Morris, USAF and picture taken during Dec. 2013 filed visit.)

Figure 5-7. Infiltration BMP to capture and infiltration of runoff from parking lots (Pictures provided by Mr. Don Morris, USAF)

Figure 5-8. Bioretention BMP to capture and infiltration of runoff from parking lots (Pictures provided by Mr. Don Morris, USAF)

Other strategies include the preservation/protection of environmentally sensitive site features such as riparian buffers, wetlands, steep slopes, valuable (mature) trees, flood plains, woodlands and highly permeable soils. Extended detention BMPs are designed to detain stormwater flows for an extended period following storm events. The volume of stormwater discharged will not be reduced as with a retention system, but if the flows are spread out over a long enough period, then the high flow rate will be reduced. For example, vegetated wetlands are natural extended detention BMPs. While retention type BMPs may be preferable from a groundwater recharge standpoint, extended detention BMPs may be more suited to soil and groundwater conditions found at HAFB. These types of BMPs are generally better suited for long-term viability than recharge-type BMPs which are subject to obstruction over time. An effective extended detention BMP for HAFB could be wetland/extended detention basins. An example of an extended detention BMP is presented in Figure 5-9.

Figure 5-9. Extended Detention BMP to capture and detain for evaporation of runoff from parking lots (Pictures provided by Mr. Don Morris, USAF)

As reported by Fuss and O'Neill (2011), 47 numbers of infiltration type BMPs (ranging from 10.6 m^3 to 1020 m^3 in volume) with the total volume capacity of 3050 m^3 and 6 numbers of non-infiltration BMPs with the total volume capacity of 2630 m^3 installed throughout the Hanscom sub-watershed between January 2000 and September 2011.

5.4.2 Environmental Water Quality

Based on the information available HAFB conducted an evaluation on baseflow contribution to stream flow, beginning with the time of pre-installation of HAFB (1938), 1990s when there was no control existed, and 2011 after installing considerable amount of recommended BMPs and compared them with the target set by TMDL plan. The results are summarized in Table 5-3 and Figure 5-10. Overall, the implementation actions are moving in the right direction towards meeting the target.

Table 5-3. Evaluation of Baseflow Conditions at Hanscom Air Force Base (Simulated using GWLF Model developed and Calibrated by Saravanapavan et al., 2000).

Year and Representing Condition	Percent Baseflow in Stream Flow (Baseflow (%) = Annual Baseflow/ Annual Total Stream Flow * 100)
1938: Pre-Urban (Before Installing HAFB)	71
1990s: Urban (Pre-TMDL Plan)	33
2011: Evaluation (10 years after Plan)	40
Target from TMDL Plan	63

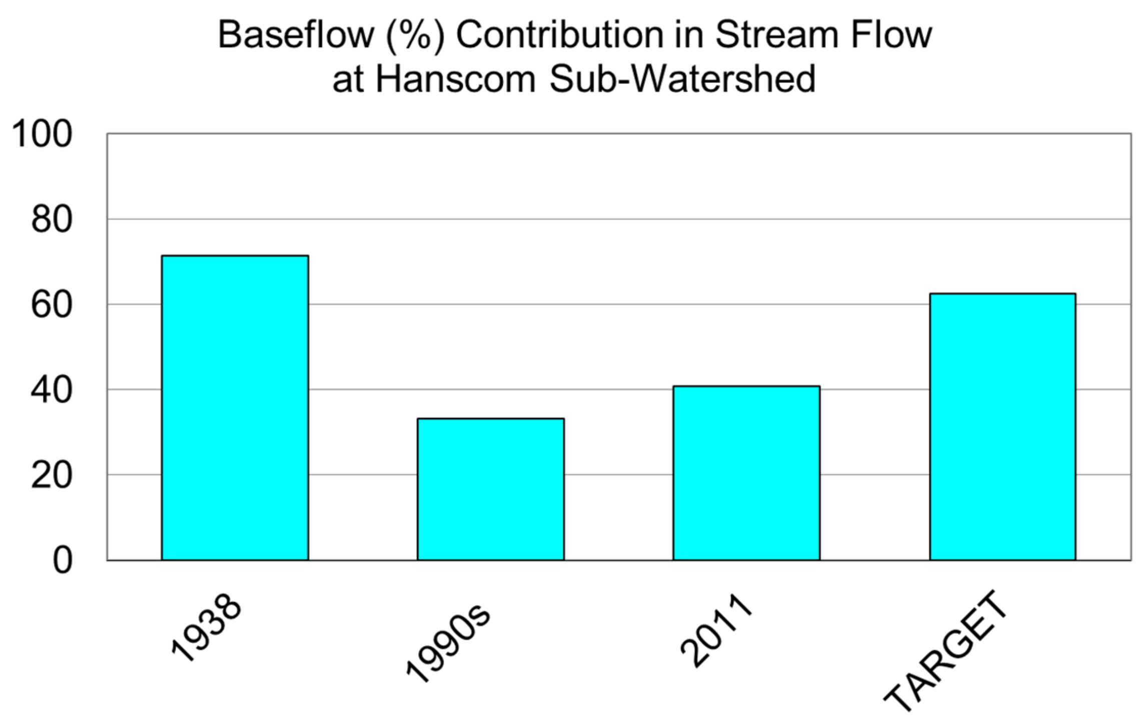

Figure 5-10. Evaluation of Baseflow Conditions at Hanscom Air Force Base (Simulated using GWLF Model developed and Calibrated by Saravanapavan et al., 2000).

In addition to baseflow analysis, an FDC was developed for the condition in 2011 as presented in Fuss and O'Neill (2011). FDC for 2011 is compared with the Pre-TMDL plan and TMDL target conditions and presented in Figure 5-11. It is clear that the implementation actions over 10 years is bringing the FDC towards the target set by TMDL.

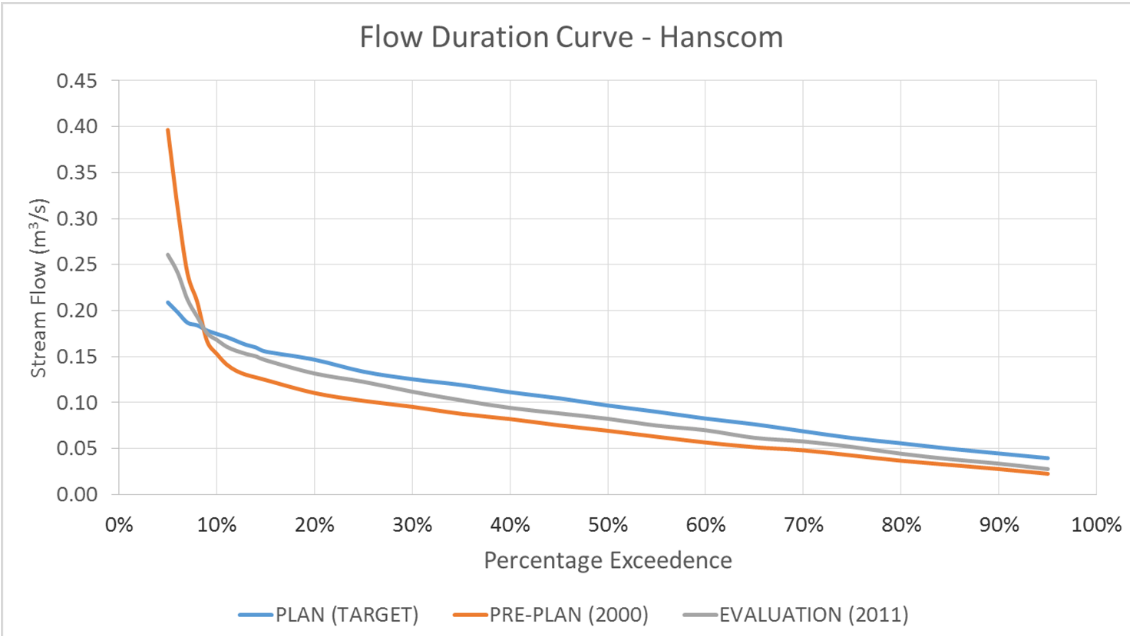

Figure 5-11. FDCs of Pre-TMDL (Orange Line), the target as per TMDL (Blue Line), and the condition at the time of evaluation in 2011(Ash Line) for Hanscom Watershed.

HAFB also conducted an evaluation by comparing the habitat condition of pre-TMDL (MRWC, 1997 and 1998, and MA DEP 2000) and post-TMDL, during the installation of BMPs. The results are summarized in Table 5-4 and Figure 5-12.

Table 5-4. Evaluation of Habitat Condition following US EPA's Bio Assessment Protocols (Barbour et al. 1999).

Year and Representing Condition	Habitat Score	Narrative Assessment
1997: MRWC: Urban (Pre-TMDL Plan)	82	Not Supporting
1998: MRWC: Urban (Pre-TMDL Plan)	74	Not Supporting
2000: MA DEP: Urban (Pre-TMDL Plan)	79	Not Supporting
2005: MA DEP: Post-TMDL Plan	101	Partially Supporting
2010: MA DEP: Post-TMDL Plan	105	Partially Supporting

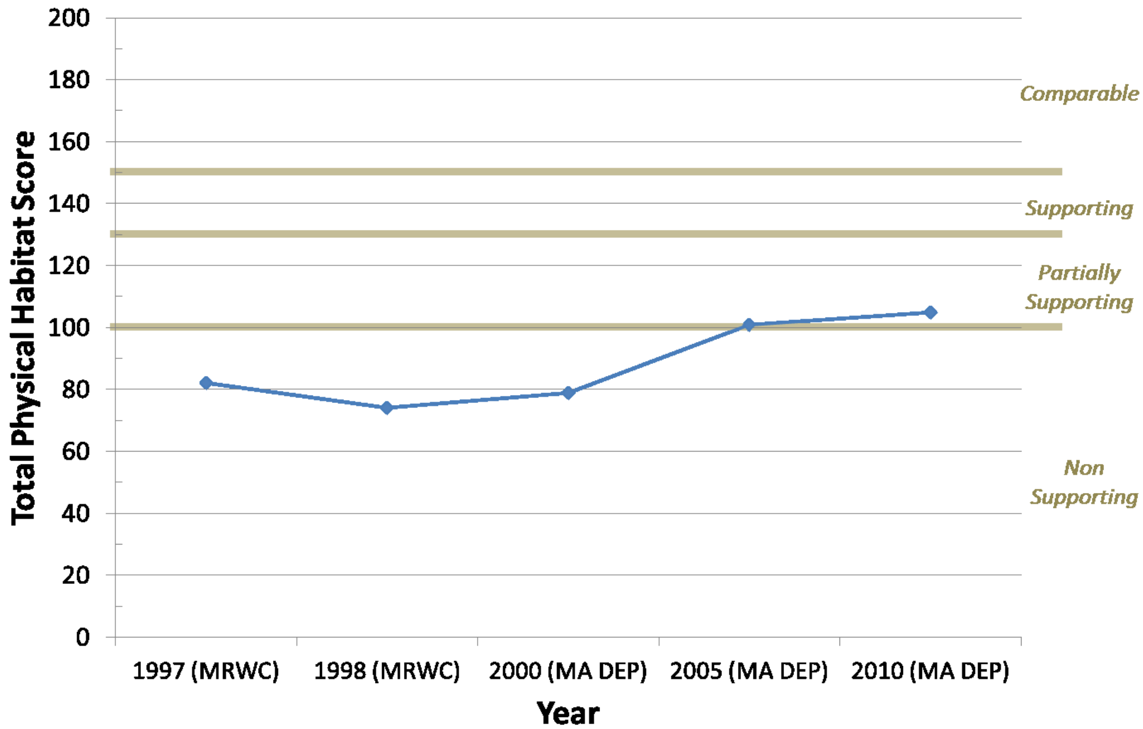

Figure 5-12. Evaluation of Habitat Condition following US EPA's Bio Assessment Protocols (Barbour et al. 1999).

The evaluation of baseflow, FDC and habitat conditions almost after a decade of implementation activities revealed that the innovative planning approach resulted in positive outcome not only in managing the hydrological conditions but also, more importantly, improving the habitat and aquatic life conditions. Continuous implementation, monitoring, evaluating and adjusting is the key process to be followed until a determination is made by the relevant authorities on meeting the water quality standard and removing the segment from the 303 (d) list of impaired waters.

6.0 ENHANCEMENTS TO MANAGEMENT FRAMEWORK

The third and final objective of this research is to further enhance the framework for use as a policy tool for hybrid planning with lessons learned from its implementation discussed in Chapter 5. A primary goal of the framework would be to provide a self-sustaining institutional structure for interdisciplinary decision making to resolve water resource issues related to urbanization at the watershed level. Previous Chapters have focused on the development (theory) and implementation (practice) of a new management framework while noting the innovative scientific contributions compiled during the process. This Chapter summarizes the lessons learned during the implementation case study and consolidates them into a refined management framework (policy) named the Grass-root Watershed Management (GWAM) Model, which will serve as a generic institutional model for urbanization impact mitigation. Therefore, an analysis was done to link the theoretical management framework into a policy tool from the practical knowledge and lessons learned from the Shawsheen. In this Chapter, lessons learned from the prospective of capacity building at watershed level are discussed and then the framework is refined accordingly.

6.1 LESSONS LEARNED FROM PRACTICAL IMPLEMENTATION

The successful implementation of the framework at the Shawsheen watershed provides valuable lessons about what constitutes an effective watershed management model. The first and foremost lesson is that the theoretical framework cannot be put into practice overnight. Citizen activities started as early as the 1970s, although nothing was well organized until the fully functional group was organized by 1998 under MWI. However, establishing the framework had started in 1995 when Merrimack River Watershed Council (MRWC) and Hanscom Air Force Base (HAFB) formed a group. Then Massachusetts Department of Environmental Protection (MADEP), Shawsheen Watershed Environmental Action Team (SWEAT) and others joined which established a fully functional unit in 1998. There clearly existed at least two stages, an organizational stage and a functional stage, which led to a fully functional institutional structure. Therefore, the lessons learned will be presented according to the organizational and functional stages. The information presented in this section comes from technical reports published by state government, MRWC, SWT meeting notes and in-person and/or phone conversation with Mr. William Dunn, MADEP (Former SWT Leader), Late Ralph Goodno (Former President of MRWC), Mr. Bob Rauseo

(Former President of SRWA) and Mr. Donald Morris (Former Environmental Flight Chief of the USAF).

6.1.1 Organization of GWAM

The existence of water resource issues were the key drivers behind establishment of the groups in the Shawsheen. As reported in EOEA (2003a), a citizen group was formed because of pollutants from the HAFB and other industrial properties in the watershed. Later this group was disbanded in the 1980s after the issues were apparently addressed through the government agencies NPDES permit program focus on large point sources of pollutants such as industries and waste water treatment facilities. Then in 1990s SWEAT was formed to clean up debris that were blocking canoeing and kayaking activities. MRWC and HAFB formed a watershed team in 1995 to begin monitoring water quality by MRWC members, which continually reporting bacteria and other contamination in the river. The MRWC has been organizing (still has as of 2018) canoe trips in Shawsheen since the late 1980s.

Although, a federal government agency, HAFB joined the environmental protection activities as a stakeholder organization located in the watershed. The real motivation behind HAFB's participation was to ameliorate potential social and legal conflicts related to HAFB's contributions to environmental degradation which had begun as a result of the construction of the base in 1942. One of the most notable issues was flooding during large storm events and its associated impacts such as road and school closures etc., (EOEA 2003a). Increased flooding also stimulated citizen interest in the form of complaints to local and state governments, as well as the issue being raised by members within SWEAT and MRWC. Clearly, local issues formed the basis of establishing the framework for watershed management. Eventually, MADEP joined the team to collect information from local volunteers as part of in implementing their 1995 watershed based water quality assessment program. Later after 1998, MADEP would participate in a much greater capacity by bringing its own resources and those of other government agencies to the team under Massachusetts Watershed Initiative (MWI).

The successful implementation of the management framework proved to be an advantage of utilizing a hybrid approach in watershed management by helping to directly address local issues through bringing essential external resources, government support and ample opportunities for stakeholder deliberation. During the establishment stage, SWT under MWI generated the platform to convene and conduct watershed management at the local level by integrating input from government agencies, typical top-down players, NGOs and local partners, typical bottom-up players, in a common forum. It is evident that SWT effectively utilized this platform for careful deliberation and for sharing and implementing the results of technical analysis which resulted in well-informed decision making.

Under the evolved SWT framework, the common platform played a key role in bringing a 3C approach of involving stakeholders to address issues related to land use change and urbanization. The other critical component for the Shawsheen case was the established partnership of two major stakeholder groups, private/NGO participants and government agency representatives. The bonding agent that led to effective partnerships under the permanent platform was established and strengthened through a facilitation process that occurred at quarterly meetings designed for systematic interdisciplinary decision making in addressing the Shawsheen's urbanization issues. Also, it is worthwhile to note another beneficial outcome of Shawsheen process related to capacity building at the local level. The MRWC, one of the local NGOs, enhanced their institutional capacity to be actively involved in the local watershed management process by hiring engineers and environmental scientists. Their capacity to understand and be directly involved in technical deliberations play an important part in making progress in the decision making process. Another valuable lesson learned relates to the SWT's process for developing and implementing an Annual Plan and a 5 year Watershed Action Plan. Both of these plans would get endorsement by the Round Table, whose membership included high-level government representatives and leaders from NGOs and a few citizen groups including the late Ralph Goodno (Former President, MRWC). This process provided two-fold positive impacts; 1) SWT's progress was dictated by their own plan with options for amending at the end of every year based on the lessons learned (adaptation), and 2) The state government allocated its resources (funding and expert support) based on these plans.

The Shawsheen's framework organization also provides valuable insights into the importance of its interdisciplinary and self-sustaining characteristics. Again watershed management activities were initiated by primarily non-government stakeholders as a result of local issues related to urbanization. Eventually, linkages between local entities and government agencies were established to bring needed external resources through appropriate programs under the federal CWA and through the state's MWI. As a result of the genesis of the organization and its focus to address multidisciplinary issues related to urbanization, a clear interdisciplinary approach was established early in the process. Flooding, low flow, aquatic life and habitat degradation, indicator bacterial contamination, river access, river clean up, etc. were considered, evaluated and addressed at the same time by the same people under the overarching goal of protecting the Shawsheen River Watershed.

There are other attributes which contributed to the successful implementation of the management framework as summarized below:

- Full-time Team Leader appointed by the state government
- Creation of Local NGO and empowering it towards co-leadership
- Committees (sub sets of the core team)
- Funding from both government and NGOs
- Networking, especially bringing the right people and resources together and acquiring approvals from government officials
- Involvement of outside experts when needed (e.g., Technical Advisory Committee for Hydrological Studies)

Full-time Team Leader (Facilitator)

Prior to the MWI, MRWC assumed the SWT's facilitator role in conducting quarterly meetings, water quality monitoring, and other activities. Mr. William Dunn of MADEP became the state's team leader for the Shawsheen watershed following his appointment by the state's Executive Office for Environmental Affairs (EOEA) in 1998. As team leader Mr. Dunn was able to dedicate his entire time for Shawsheen's watershed management activities. His duties included, but were not limited to:

- Organizing and conducting the quarterly meetings and committee meetings including record keeping;
- Coordinating team funded projects and progress reviews with respective agencies and consultants;
- Acting as an intermediary between the Team and the Round Table by providing progress reports on team activities and conveying Round Table decisions and recommendations to the team;
- Enlisting and coordinating support from other government agencies; and

- Supporting team in external fund raising, etc.

There was unanimous agreement among all former members of the SWT who were consulted, that the team leader was one of the major contributing factors to the Shawsheen's success. It was further acknowledged that the team leader played a key role in resolving conflicts and confusion (as further discussed in the next section). Similarly, from the other cases analyzed in this research, Ipswich (similar to Shawsheen under MWI) and Ohio (Koontz and Newig, 2014) with full-time team leaders and an active facilitation process, indicated greater success than those cases that did not, which generally failed. Therefore, a dedicated coordinator with the capacity to also serve in a facilitation role is deemed to be an essential element of GWAM.

Co-leadership by NGO

As indicated, the MRWC assumed the facilitator role until a state appointed full-time team leader, Mr. Dunn, took over this responsibility. Later in 2001 SWEAT became part of the SWRA, a state sanctioned and recognized full statue non-governmental and non-profit organization, (EOEA, 2003a). However, SRWA started its formal activities, including establishment of a board of directors and ability to enlist membership, in 1999. At his point SRWA assumed a co-leadership role in working with the team leader on setting agendas for quarterly meetings, prioritizing watershed issues, selecting members for committees, and most importantly bringing local resources such as funding, school facilities, the organization of town hall meetings, educational workshops, trainings, etc. to the process.

Based on follow-up conversations conducted as part of this research, both Mr. Dunn and Mr. Rauseo agreed that the role of co-leadership was valuable and helped to relieve initial tensions caused by limitations on technical capacity at SRWA. Others viewed SWRA's co-leadership as being instrumental in in bringing local voices onto equal footing with the government partners. All contacted agreed that co-leadership provided SRWA motivation and a sense of ownership of the process itself. It is important to note that recent policy guidelines by Organization for Economic Co-operation and Development (OECD) (Akhmouch and Clavreul, 2016) on stakeholder engagement include, "Inclusiveness and Equity" as one of the six necessary conditions for inclusive water governance. Co-leadership provided the mechanism for a local NGO to be included and treated as an equal partner along with government officials. Therefore, co-leadership by a local

NGO is recognized as an important element and another necessary condition to be included in GWAM.

Committees

Several of the special features observed at SWT are committees, task committees (referred as sub-committees), and stream teams. Committees were permanent sub-sets of the team. For example, the steering committee was created for developing annual planning and 5 Year plans. This group met several times between quarterly meetings during the period of plan development and briefed the general body for any decision to be made. Committees did not make decisions but provided the necessary work, analyses, and information needed on which decisions would ultimately be made. Task committees were considered temporary since they were formed for a specific task and once the task was over, their activities discontinued. For example, the recreation map task committee was formed to develop a watershed wide recreational map and worked with a consultant over a year (through several meetings and field visits etc.) to accomplish the task. Stream Teams were several small groups that were engaged in volunteer monitoring of a selected stream, generally a tributary of Shawsheen.

The purpose of these committees was to make sure of continual progress in the variety of topic areas while also supporting effective member participation at the quarterly meetings during which new findings and results were discussed and deliberated. Post-project conversations conducted for this research confirmed that members considered the committee approach to be very effective especially later in the process when there were increasing demands to secure the time on a quarterly meeting agenda. Among the total of 12 cases considered in this research, only the Shawsheen and Water Watchers cases used such an approach. The committee process in the Shawsheen appears to have been an efficient way to manage a tremendous amount of information covering a variety of topics and disciplines. However, information in the literature is still too limiting to confidently state whether or not the committee approach is an absolute necessity for a successful watershed management process. Because of the multitude of issues and number of disciplines involved with addressing urbanization impacts, this research recognizes the value of the committee structure and therefore, identifies it as a potential necessary condition for GWAM so that it can be carefully considered as a potential element at the beginning of the watershed management process.

Funding from both government and NGOs

For the Shawsheen, the state government, EOEA, had a $100,000 yearly allocation for priority watershed projects identified by the SWT. From 1998 through 2003, the team received $430,000 in total project funding to address its priorities (EOEA, 2003a). During the same period, the team members also raised more than $ 425,000 from non-governmental partners as matched support for the team's priorities. These amounts exclude the considerable value of time and effort provided voluntarily by the team members on a variety watershed work including watershed wide physical, chemical, and biological monitoring, habitat and biological assessments, pollution remediation planning and implementation, GIS data acquisition, Total Maximum Daily Loading (TMDL) development, water balance analysis, flood mitigation planning, riverbank erosion mitigation, river clean ups, and development of Shawsheen recreation map.

It is clear, that sustained funding from both government and NGO sources over an extended period of time was a critical contributing factor to the success reported in the Shawsheen. While it is readily apparent that the Shawsheen would not have had the same level of success without government funding, it is difficult to ascertain how instrumental the NGOs" funding was in terms of effecting the level of success. NGOs funding came as matching funds required for government funding or as supplementary funds when government funds were insufficient to meet priority needs. However, the equal amount of funding from NGOs cannot be ignored for its importance to the success of the Shawsheen. When NGOs brought funds to the table, it gave them more ownership and resulted in a more inclusive and equitable partnership for the process. An equitable partnership among all stakeholders is a necessary condition (Akhmouch and Clavreul, 2016) for effective and inclusive stakeholder engagement in water governance. Koontz and Newig (2014) reported that funding was a key factor for success in Ohio's program. The cases that received government funding resulted in more successful implementation of recommended actions while those cases with no government funding had more challenges and less success in implementing needed actions. GWAM includes funding from both the government and NGO as a necessary condition.

Network and External Assistance

The Shawsheen's innovative interdisciplinary planning approach to address aquatic life impairment through using hydrology as a surrogate was possible because state and federal government members succeeded in convincing high-level government officials in granting approval. The approval was challenging for two reasons; 1) The approach was unique (nonconventional) and unlike any approaches previously used for of developing acceptable TMDLs in the country, and 2) At EPA there were ongoing legal issues and policy deliberations related to how flow could or could not be used in the TMDL process (a legal action on a flow TMDL involving several permitted water withdrawals spurred this internal debate). However, after a long deliberation, state and federal approvals of this approach were granted. Later, the states of Vermont and Ohio also applied this approach to address aquatic life impairments as presented in Saravanapavan et al., (2014).

The innovative approach resulted in a detailed implementation plan that resulted in environmental quality improvement as reported in Chapter 5. Another factor that assisted the SWT in carrying out this approach was the formation of a Technical Advisory Committee (TAC) comprised of outside experts. The TAC was not only providing peer review to the hydrological studies but also provided endorsement to the merits of the approach and its outcome. That allowed the team members, especially those with limited technical capacity, to feel more confident in accepting the outcome without being overly concerned about the partiality of the government agencies. The conflict of opinions related to the hydrology surrogate approach and its results were resolved by the outcome of the water balance study and its endorsement by the TAC. Also, the same water balance study was the basis of further analyses for TMDL development and implementation plans.

In the literature, Koontz and Newig (2014) identified "Network", as the relationships between local stakeholders and state employees that especially helped to gain state endorsement of watershed plans and moreover to secure state funding for implementation. Akhmouch and Clavreul, (2016) identified that "capacity and information" is a necessary condition for stakeholder engagement in inclusive water governance. Clearly, success in the Shawsheen would have not occurred without Networks and External Assistance. Therefore, these features are included in GWAM as a necessary condition.

6.1.2 Functioning of GWAM

The detailed evaluation of the Shawsheen's approach discussed in Section 4.4 reveals that the systematic steps of problem identification, problem recognition, problem investigation for implementation planning, and problem solving through implementing actions provided the necessary opportunities for facilitated deliberation of the issues over time. In other words, facilitation was integrated into the process as knowledge was adopted through data collection, scientific studies and experience shared by members. Additionally, this process required integrating related regulations and program policies, resources and participation of stakeholders in decision making at every step.

For example, after analysis of bacteria monitoring data during the problem identification step, stakeholders decided to address the bacterial contamination issue through a TMDL analysis approach in the problem recognition step. Reaching this decision involved working with MADEP and US EPA to secure an allocation of needed resources for the TMDL analysis and exemplifies an effective process of integrating local decision making with the state and federal TMDL program objectives. Similarly, other steps in the process helped SWT to identify, justify and bring needed external resources to for effectively address the local watershed issues in the Shawsheen. While each of the four steps represented individual phases of solving identified issues, the quarterly meetings provided the means for linking the steps together and advancing the decision making process.

The adaptability of the Shawsheen's approach is revealed in the process of addressing aquatic life impairments. During the second step of problem recognition, the SWT initially decided to address the impairments by developing a sediment TMDL. However, upon consideration of new information during TMDL development, the SWT decided to abandon the TMDL effort and return to the first step for further data analyses and refinement of the problem identification. These systematic steps effectively guided the SWT in addressing watershed issues and provided an effective framework for timely and sound decision making on the appropriate use of resources. This research recognizes that the process needs a certain amount of flexibility and adaptability that will depend on the complexities of the issues being addressed. Stakeholders may decide that steps could be bypassed for addressing an issue with a straightforward solution whereas for other more complex issues stakeholders may decide that a step should be repeated.

Another critical lesson learned from the Shawsheen application is that conflict and confusion resolution among stakeholders is a necessity for effectively making progress in addressing the issues. Due to its significance, the conflict and confusion resolution element is addressed in a separate section as follows.

6.1.3 Conflict and Confusion Resolutions

One of the important challenges in sustaining the management framework was having the means to keep differently motivated stakeholders together on identifying solutions for achieving the primary single goal of protecting the watershed. Given the complexities of addressing water resource issues and the potential impacts of management solutions on stakeholder interests, conflict and confusion among stakeholders is a factor that needs to be addressed throughout the process.

For flooding and low flow issues, a conventional approach of addressing high flows or flood flows through mechanisms such as peak shaving or by enlarging culverts or channels did not holistically address the issue because it would essentially transfer the problem further downstream. In the Shawsheen, this conventional solution resulted in finger pointing among watershed communities, especially from those in the middle of the Shawsheen watershed. The communities of Tewksbury and Andover that had been affected by flooding issues, had the position believed that their entire problem was caused by the USAF and the towns of Bedford and Burlington. In return, these entities clearly denied taking full responsibility and pointing out that they too had flooding problems.

Another flow related conflict was caused by the low flow issue. SRWA was the organization that brought the low flow issue to the SWT because a few members who had been canoeing/kayaking the river from childhood were frustrated by the non-navigable state of certain segments of the river in the late 1990s. Although the flow data supported the existence of severe low flow conditions in 1999, the municipality members refused to accept the validity of this issue and cited global and regional climate change conditions as the cause. A driving reason underlying their refusal to acknowledge this issue related to fears that the controls needed to adequately address the issue (increased stormwater volume recharge) would cost more than conventional peak runoff flow controls. It appears that a few town engineers stopped attending the team meetings due to this issue. Fortunately, they returned to the meetings after they were invited to participate in TAC overseeing hydrological studies.

As a part of resolving this conflict, as well as addressing the flow issue, SWT conducted a water balance study. The outcome greatly increased understanding among all stakeholders and not only confirmed the significance of HAFB's contribution to watershed flow issues but also quantified contributions to flooding and low flow conditions from other watershed source areas and conditions (e.g., developed lands). The study was instrumental in shifting the focus from peak shaving only to more holistic watershed solutions that included increased stormwater infiltration (low flow) and detention storage (flooding). Not only did the study and deliberations result in HAFB accepting the issue as valid, but it also led HAFB to taking immediate steps to begin resolving the issues. Another beneficial outcome resulting from the flow issues conflict resolution process was adoption of a "no net runoff policy", which specified that all future development and redevelopment project implement best management practices (BMP) to mimic pre-development hydrology conditions. Also, many municipalities within the watershed started to implement BMPs on their own properties (e.g., town hall, schools etc.) to capture and ideally infiltrate runoff from their impervious surfaces.

The confusion among stakeholders surrounding the challenges of TMDL development for the aquatic life/habitat impairment actually resulted in the SWT changing course and choosing to develop and apply an innovative approach (Saravanapavan et al., 2014) that not only benefitted in effective watershed planning in Shawsheen but also was subsequently a useful approach for many other places in the USA. As mentioned previously, if there had not have an interdisciplinary forum to address the flow issue and aquatic life/habitat issue at the same time by the same people for the same goal, this innovation would not have been possible.

Another area of confusion related to interpreting the level of bacteria control needed based on the bacteria TMDL following government approval. While bacteria discharges from all wastewater treatment facilities were adequately addressed through NPDES permitting, the TMDL still specified substantial reductions of bacteria load from stormwater runoff, illicit discharges of sanitary sewage and non-point sources such as failing septic systems. SWT deliberations because of this lack of clarity (i.e., confusion), resulted in a pilot program study being conducted for selected a control area that involved a source identification investigation including targeted bacteria monitoring, a land use source loading analysis, implementation of control measures and post-implementation bacteria monitoring to evaluate the effectiveness of the control measures implemented. Later the lessons learned from the pilot study were incorporated into a watershed wide implementation plan that was adopted by all stakeholders within their individual programs. Successful implementation of bacteria control measures resulted in an immediate water quality response of improved conditions within the river system as has been exhibited by recent data collection results. Table 6-1 summarizes the conflicts and confusions.

Table 6-1. Summary of the topics of conflicts and confusion, resolution mechanism applied and the outcome of resolutions during the field implementation at Shawsheen.

<table>
<tr><th>Conflict/Confusion</th><th>Resolution Mechanism</th><th>Resolution Outcome</th></tr>
<tr><td>Acceptance of Baseflow Issue</td><td rowspan="2">• Conducted Water Balance Modeling Study
• Transparent Update on Progress during Quarterly meetings from the start to the end
• Review of Study Result by Technical Advisory Committee (Academics and Professional)</td><td rowspan="2">• Baseflow was accepted as everybody’s problem.
• Hanscom Air Force accepted their large contribution to the problem and moved forward with voluntary implementation.
• Other Towns Adopted no-net runoff increase policy.</td></tr>
<tr><td>Relative contribution of towns on flooding problem (All put the blame on Hanscom ignoring their own)</td></tr>
<tr><td>Unable to develop Sediment TMDL as originally planned</td><td>• Innovative Interdisciplinary TMDL
• Measurable Flow Targets that are used both flood control and aquatic life impairment</td><td>• Implementation of stormwater control BMPs at Hanscom Air Force Base</td></tr>
<tr><td>Don’t know how to meet the TMDL in reducing bacteria load to the river</td><td>• A study was conducted to understand the implementation actions in selected drainage area
• Transparent Update on Progress during Quarterly meetings from the start to the end</td><td>• Implementation Plan was adopted by everyone.</td></tr>
</table>

A close examination of conflict and confusion resolutions in the Shawsheen watershed process revealed that science played a key role in maintaining constructive dialogues among differently motivated stakeholders. The continued focus on underlying science provided needed facts, understandings, supporting data, and knowledge to make well-informed decisions. The integration of science began when SWT documented habitat and aquatic life impairments in the Shawsheen headwaters based on past monitoring which resulted in placing these affected waters on the list of the State’s impaired waterbodies, under the Federal Clean Water Act. The listing of the waters as impaired served as an impetus to conduct other investigations such as expanding the scope of the water balance hydrological study, which was originally intended for solving flooding issues. Consequently, the expanded scope of the study helped the team understand and accept the validity of the habitat and aquatic life issues as well as its association with imbalances to the hydrological regime. At the same time, science was integrated through targeted data collection on habitat and invertebrate assessments, which further confirmed to the SWT the existence of these impairments which was essential information for stakeholders to recognize and accept the impairment as one of the priority issues.

The team's decision to develop a TMDL as the most appropriate avenue to address this aquatic life/habitat issues represented a turning point in the process. The SWT was guided by the scientific investigations and continuous evaluations of information and thorough deliberations on the best options to develop the TMDL. Ultimately the SWT decided that an innovative approach would be the best option for the Shawsheen. Following GWAM's integrated interdisciplinary approach designed for collaboration among diverse members with varying background and professional disciplines, the SWT decided on using hydrology as a surrogate to account for all known and unknown contributing sources. The innovative approach would address multiple urban stressors causing aquatic life impairments and would be amenable for TMDL development. At this time, it was the first of its kind in the United States and would be later implemented in many other watersheds in the United States as reported in Saravanapavan et al., 2014. Again it is worthwhile to note that one of the common limitations of the over centralized top-down approach is the tendency to focus on environmental objectives though entirely scientific or technical lenses without much consideration of local societal impacts or realities of implementing the recommendations. However, in the Shawsheen, the use of scientific information was an essential and instrumental mechanism for sustaining the problem solving process by keeping stakeholders in engaged in constructive deliberations and decision making.

The shawsheen case revealed that the scientific approach applied in the failed top down cases is not the problem itself but that the problem in these failed cases is related more on how and where science is applied in the process. In the Shawsheen, the call for scientific support came from bottom at watershed level in response to conflicts, confusion and the need for more information while the over centralized approach implemented a type of one fits all approach to a local issue without local engagement. This major lesson is essential for success in water management work and as key component of applying GWAM. GWAM is a policy tool based on the theory and empirical information developed from many case studies around the world and has been validated and refined through practical knowledge gained from its application in the Shawsheen, USA. But each and every application of their own should go through a systematic evaluation before implementation.

The next section provides the details on the refined GWAM framework and some guidance for future application based on the lessons learned.

6.2 THE REFINED GWAM FRAMEWORK

Building on the knowledge learned from the practical implementation for the Shawsheen watershed, the GWAM model has been refined to accommodate the capacity building, organizational capacity, functional capacity and the mechanism to sustain those capacities, at the watershed level. Several outcomes, previously reported in this document, will be repeated and summarized in this section to provide a holistic understanding of GWAM as a generic watershed management model. It is expected that the refined and final GWAM framework can be readily employed as a policy tool to build the capacity for other watersheds faced with needing to address urbanization impacts.

6.2.1 Organizational Capacity

The application of GWAM for The Shawsheen verifies (as presented in Section 6.1.1.) that government policies, programs, and regulations (external resources) should be appropriately integrated with local knowledge and input (based on watershed issues) for successful establishment of the **structure** of the framework. Accomplishment of this structure requires:

- Common **platform** (or an establishment) to convene,
- Committed **partnership** from at least two major groups of the stakeholders, governmental and non-governmental organizations including local groups and citizen, and
- Effective **facilitation** of sustainable and interdisciplinary watershed management.

Also, it was learned that the **process** established through short-term (annual) and long-term (5 year) planning helped to support continuing efforts to bring external resources for sustainable watershed management to the Shawsheen. This supports the logical conclusion that GWAM should establish an appropriate organization (structure and process) to appropriately conduct the function of addressing watershed issues in a sustainable and continual manner. While confirming GWAM's sufficiency in meeting the necessary conditions formulated in Chapter 3, the lessons learned from the Shawsheen, presented in detail in Section 6.1.2., have resulted in adding the following necessary conditions:

While confirming the sufficiency in meeting the necessary conditions formulated in Chapter 3, the lessons learned from Shawsheen, presented in detail in Section 6.1.2., added the following necessary conditions.

- Full-time Team Leader
- Co-leadership by NGO
- Committees
- Funding from both government and NGOs
- Network and External Assistance

Overall scheme of GWAM organization is presented in Table 6-2 with organizational capacity, structure, process and necessary conditions to conduct its function of addressing the urbanization issues through interdisciplinary approach in a self-sustaining institutional framework.

Table 6-2. Summarized representation of GWAM with structure, process and the necessary conditions for effective watershed management.

STRUCTURE	**Common Platform**	Provides the institutional set up to all parties to be invited, convene, deliberate and ensure meaningful involvement in the decision-making.
	Partnership	Provides the necessary balance of differently motivated stakeholders, from government and private/citizen organizations, to effectively be engaged in decision making
	Facilitation	Provides the necessary facilitation for stakeholders engaged in the exchange of ideas through interdisciplinary thinking at every step and to encourage democratically acceptable decision making towards addressing the issues to protect and restore waterbodies.
PROCESS	**Short-Term Planning (e.g. Annual)**	To provide details on the environmental issues and a list of prioritized projects/action for the term considered. It is a working document on the issues and status.
	Long-Term Planning (e.g. 5-Year)	To guide local environmental efforts over a long term. It includes goals, status, direction and resource for the next term.
NECESSARY CONDITIONS	**Strong knowledge base**	To help design and implement informed water management policies and strategies
	Integrated action across all issues	No singular solutions by a single discipline are sought without involving all stakeholders, with whom all impacts and improvements across the spectrum of water management are evaluated
	Promotion of community participation	To enhance stakeholder involvement in the management decision-making
	Network and External Assistance	To bring the right people (when needed like TAC) and resources as well as acquiring the approvals from government top levels
	Stable framework	To overcomes fragmentation and overlap of responsibilities
	Institutional arrangements	Such as cost-sharing programs, tradable discharge permits, local government planning powers, voluntary actions, regulatory practices.

	Organizational structures	Such as democratic and accountable systems, and access to high levels of government; and maintenance of effective coordination of civil and professional science
	Shared visions	Across all institutional levels, based on careful problem analyses
	Full-time Team Leader	To facilitate and coordinate watershed management activities and acquiring needed resources from the government
	Co-Leadership by NGO	To help facilitating and coordinating watershed management activities and acquire needed resources from NGOs
	Committees*	To provide support in coordinating specific tasks beyond the time available for regular team meetings and report to the team
	Funding from Government and NGOs	To provide the fuel for overall watershed management effort. The contribution from both the government and NGOs would provide appropriate inclusiveness and equity for all stakeholders.

*Optional Necessary Condition that requires clear evaluation and justification before using it as a necessary condition.

6.2.2 Functional Capacity

The functional capacity of GWAM should have two major capabilities: 1) To address the issues through a set of systematic steps of decision making; and 2) The mechanism to sustain the decision-making process.

The steps could be as simple as four steps; problem identification, problem recognition, problem investigation for implementation planning, and problem solving through implementing actions, as presented in the new framework or more detailed steps as presented in US EPA's watershed management plan guidance (US EPA, 2008). The key is that these sets of steps should help facilitate constructive problem-solving deliberation of the issues over time while adapting as new knowledge is acquired through data collection, scientific studies and the experience and input shared by stakeholders. In addition, it requires integrating related regulations, programs, resources and stakeholders into the decision-making process at every step. While each step represents an individual phase of problem-solving for identified issues, the regular meetings provide the forum and opportunity to link various components in the proper context for advancing a well informed and holistic decision making process for the watershed. Applying systematic steps provides a useful framework for guiding stakeholders in addressing issues and making well informed decisions about resource allocation.

Another functional capacity is having the means to successfully integrate science into decision making as it was described in the Shawsheen application. To successfully implement watershed planning and management through GWAM, it is important to have the appropriate structure and process in place at the beginning. In the meantime, it is equally important to sustain the structure and processes for a long enough period to accomplish meaningful planning, actions and management to address the watershed issues. The most important challenge in sustaining GWAM is to keep differently motivated stakeholders together and focused on problem solving to achieve the primary goal of protecting the watershed. Differences in understanding, knowledge, job functions, education level, intended use of water resources, and resources availability make stakeholders tend to differ in opinion, priority, and decision making (Table 6-3).

Table 6-3. Typical stakeholders and motivational factors in a GWAM unit.

Group of Stakeholder	Motivational Factors and Interest
Government Stakeholders	▪ Implementing and enforcing environmental regulations
	▪ Scientific studies, research and development
	▪ Natural resources protection
	▪ Disaster prevention/mitigation
	▪ Fish and aquatic life protection
	▪ Sustainable development planning
	▪ Research opportunities
	▪ Complying with regulations
Non-Government Stakeholders	▪ Protect watershed
	▪ Disaster prevention
	▪ Promote recreational use
	▪ Natural resource protection
	▪ Job and consulting opportunity
	▪ Political benefits
	▪ Other uses of water resources

As investigated and revealed in the Shawsheen watershed case, science played a key role in keeping differently motivated stakeholders together and engaged in the process. Stakeholder participation in the identification of scientific information needs and their review of new science-related information let to increased understandings of the issues and an acquired knowledge for making well-informed decisions. Also, this process was especially essential in resolving the conflicts and confusions among stakeholders on “what to do” situations. The process of obtaining the necessary scientific information helped to facilitate the stakeholders arriving at well informed and educated decisions that allowed the process to progress. With the integration of scientific data collection, modeling analysis, TMDL development, innovative tools, and gap analysis into deliberative stakeholder discussions, the diverse stakeholders were able to dispel early misunderstandings and to acquire the necessary knowledge to comfortably support decisions. Care should be taken not to provide scientific information in an effective manner and not overwhelm the local stakeholders as has been reported as a limitation in the literature for top-down approach cases. As such, the request for scientific support should come from bottom rather than from the government, especially when a decision requires such support. However, regular updates on scientific development or training as a part of capacity development could be originated from the government.

6.2.3 Capacity Building for GWAM

The first and foremost activity is to identify issues and all stakeholders. Without issues and stakeholders, GWAM cannot proceed. The next step is to assess the existing capacity. The capacity assessment should include the following.

1. Assessment of Organizational Capacity
    a. Structure (3 Elements)
    b. Process (Short and Long Term Planning)
    c. Necessary Conditions
2. Assessment of Functional Capacity
    a. Steps of Decision Making Process
    b. Integrating Science in Decision Making

The existing capacity should be compared to the capacity needed to implement GWAM and the gap should be identified. At this stage, it is important to see whether any adjustment is required for GWAM components, especially on necessary conditions. If justifiable, the adjustments should be made before applying it.

Once the gap is identified and the necessary adjustments are made, the process of filling the gap should begin. Organizational capacity should begin with building the structure and process and then followed by a sufficiency evaluation of necessary conditions. Functional capacity should be built by beginning the function of addressing the issues.

7.0 CONCLUSIONS AND RECOMMENDATIONS

A new management framework (theory) was developed to provide a self-sustaining institutional set up for addressing urbanization related water resource impacts through interdisciplinary decision making at the watershed level. Then the framework (practice) was validated at the Shawsheen watershed in Massachusetts, USA for the process of solving several issues related to extensive urbanization in the watershed. Based on the lessons learned from the validation process, the new management framework (policy) was enhanced to become a general hybrid model, Grass-root Watershed Management (GWAM) Model with a clearly defined structure and processes in place to perform the function of addressing watershed issues with the necessary mechanisms to sustain the structure, processes and function needed to accomplish identified management goals.

The GWAM represents the first hybrid model that is specifically designed for mitigating urbanization impacts in watershed management at the watershed level. As the model is designed to overcome known limitations identified from both the top-down and the bottom-up management approaches, long-term sustainable watershed management now becomes a possibility. The successful field validation at the Shawsheen River Watershed also serves as an example of a successful sustainable watershed management process that is suitable for other watersheds dealing with urbanization-related water resource impacts. The research proposes a new planning approach through the application of the new management framework. GWAM emphasizes the importance of robust stakeholder participation with interdisciplinary thinking at every step of decision making throughout the process to meet the challenges of addressing the complex physical and ecological issues associated with urbanization.

7.1 RESEARCH IN SUMMARY

Urbanization often resulted in flooding, water quality impairments, stream morphological instability, deficits in groundwater, and habitat and aquatic life impairments. The impacts and their causes are complex and inter-related in nature, and thus require an interdisciplinary approach to achieve effective solutions through sustainable watershed management. The primary challenges for accomplishing sustainable and effective watershed management are securing the necessary external resources to adequately address local watershed issues while also systematically providing support for robust stakeholder engagement and participation.

Watershed management has witnessed several paradigm shifts over the last several decades. A new paradigm called the "hybrid" approach, which is a combination of both the top-down approach and the bottom-up approach has emerged only recently in watershed management. Despite the positive conceptual recognition, real-world applications on how the hybrid approach could potentially help addressing urbanization have been essentially non-existent. Also, there exists very limited knowledge on how a functional institutional model can be established for effective watershed management, specifically on a self-sustaining institutional structure that supports interdisciplinary decision making. Limited knowledge especially gained from practical case studies exists regarding the mechanisms of feasible decision-making processes and sustaining such mechanisms at the watershed level. Most importantly, to date, no hybrid model has been proposed or developed to specifically address the challenges associated with urbanization.

Towards contributing needed knowledge in this field, this research sets forth the three following objectives:

1. To develop a new management framework that can overcome the limitations of both top-down and bottom-up approaches and to provide a self-sustaining institutional structure for interdisciplinary decision making at the watershed level.

2. To test and validate the new framework on a real world field application.

    - Analyze the linkage of issues and address them through interdisciplinary approach for improving environmental water quality.

    - Investigate needed components of an effective decision-making process and the mechanisms to sustain it.

3. To further enhance the framework with lessons learned from implementation.

7.1.1 Formulation of New Management Framework

The first objective of this research is to develop a new management framework (theoretical) that overcomes the limitations of both top-down and bottom-up approaches and to provide a self-sustaining institutional structure for interdisciplinary decision making at the watershed level.

Detailed literature reviews were conducted to gain understandings of the strengths and weaknesses of top-down, bottom-up, and hybrid approaches employed in watershed management with specific focus on addressing issues associated with urbanization. Four international cases representing the top-down approach (Lower Saxony, Germany; Green Revolution Project, Punjab, India; Neuse Watershed Planning, USA; and Tapak River Water Management, Indonesia) and another four cases representing the bottom-up approach (Ohio Watershed Partnership, USA; Water Watchers, Kwinana WA, Australia; Punjab Rural Water Supply, Pakistan; and Mae Sa Watershed, Thailand) were identified from scholarly literature published in peer reviewed journals and books. A Strength, Weakness, Opportunity, and Treat (SWOT) analysis were carried out on all eight cases. The new management framework was formulated by integrating the identified strengths while excluding identified weaknesses or major causes of weaknesses. The following three components of the new framework was formulated as summarized below.

- Common **Platform** – provides the institutional set up for all parties to convene, deliberate and ensure meaningful involvement in the decision-making.
- **Partnership** – provides the necessary opportunity for differently motivated stakeholders to be effectively engaged in decision making.
- **Facilitation** – provides the necessary facilitation for stakeholders to engage in the exchange of ideas through interdisciplinary thinking and deliberations at every step and to reach well informed decision making towards addressing the issues of protecting and restoring waterbodies.

The analysis of all eight cases revealed that none had demonstrated either integrated actions among participating government agencies or an interdisciplinary approach. These two features were identified as essential features for achieving sustainable watershed management to address issues associated with urbanization. Also, none of the four bottom-up cases reviewed had mechanisms to sustain the process of planning and implementation of recommendations. Limitations in the eight cases reviewed left it unclear as to how effective the three elements of new management framework would be to address interdisciplinary approaches in a self-sustaining set up. Therefore, the literature review was further extended to gain understanding on the state of interdisciplinary approaches and self-sustaining institutional models and to identify the necessary conditions for developing such systems. The necessary conditions identified were then incorporated into the three major elements to form the new management framework.

In summary, the new management framework was formulated with three major elements, common platform, partnership, and facilitation that integrate the strengths of both top-down and bottom-up approaches and a set of necessary conditions to achieve a self-sustaining model that provides an interdisciplinary approach.

7.1.2 Field Validation of Management Framework

The second objective of this research is to validate the theoretical new management framework through a practical real-world application to address water resource impacts related to urbanization using an interdisciplinary approach while also further investigating necessary mechanisms for a sustainable decision making process. The process for selecting the validation case involved the review and evaluation of four candidate watersheds (Ipswich, Massachusetts; Penjajawoc, Maine; Piscataway, Maryland; and Shawsheen, Massachusetts) located in the eastern United States, with similar climate and development conditions, and for which watershed management plans to address urbanization issues were developed. The candidate watersheds were identified from a review of published watershed management related project reports.

The evaluation comprised conducting a baseline analysis to compare these cases within the context of identify the best case for validating the theoretical framework through a practical application in a real-world setting. The cases were evaluated for the presence of major elements and the necessary conditions identified in the theoretical framework and on each case's suitability for a detailed investigation and gaining knowledge. Also, an examination of environmental quality improvements resulting from related watershed planning and implementation activities was conducted. Ultimately, the Shawsheen watershed, Massachusetts, USA case was selected because of its high compatibility with the theoretical framework especially the systematic decision-making process that led to actual environmental improvement in the watershed. Finally, the new framework was validated using the Shawsheen watershed case and was evaluated in great detail for its capacity in mitigating adverse urbanization impacts. For this purpose numerous sources of information/documentation were consulted including published articles, technical reports, meeting minutes/notes, and the notes from in person meetings and phone conversations.

The Shawsheen watershed has experienced intensive urban developments since the 1940s, causing deteriorations in the physical structure and water quality conditions of the stream system. The characteristics of the components of the framework were implemented in the watershed to help with the management process, especially to help address the multidisciplinary water resource problems that are typical of the urbanization process. For this objective, a detailed investigation of the Shawsheen process was carried out using operational data and information for a 5year period (1998-2003). The investigation focused on the major elements including common platform, partnership, and the facilitation mechanisms to gain a thorough understanding on the structure, process and function in the Shawsheen case. The step by step problem solving process used in the Shawsheen to address the three issues; flooding, aquatic life, and bacteria, were analyzed to assess the processes of stakeholder participation, conflict and confusion resolution, decision making. This assessment was conducted through a careful evaluation of meeting minutes/notes and the notes from in person meetings and phone conversations. In December 2013, a field investigation was carried out to witness the results of the implementation actions.

During the detailed investigation, it was confirmed the existence of the characteristics of the major components in Shawsheen that was entirely consistent with the new framework. Common platform was to convene and conduct the watershed management at the local level by integrating the input from the government agencies, typical top-down players, and NGOs and local partners, typical bottom-up players. It was very clear that the platform was used for careful deliberation and for sharing information and results of technical analysis which resulted in well-informed decision making. The other component was the established partnership of two major stakeholder groups. The first group was composed of private residents, environmental stewards, watershed groups and non-governmental organizations, the key group that drives the bottom-up management. The second group was composed of government representatives, who are often responsible to implement and enforce regulations, typically through top-down management. Simultaneous participation of these groups in addressing these identified issues greatly improved the atmosphere for constructive dialogues. Although the two groups have different motivations, they shared the same goal of problem solving for watershed protection and restoration which allowed them to build a sustainable partnership under the new management framework. The bonding agent of the partnership was the facilitation through quarterly meetings, and the systematic interdisciplinary decision making process in addressing urbanization issues at the Shawsheen. The characteristics of the new framework at the Shawsheen River Watershed highlighted the benefits from an interdisciplinary management approach, in which scientific analysis played a critical role in all aspects of the process, especially for resolving conflicts, confusions and concerns among stakeholders and helping them to move toward agreements.

The Shawsheen stakeholders overcame the complexities and considerable challenges of adequately addressing the aquatic life impairments by developing an innovative analysis approach. This approach was formulated using sound science and after lengthy stakeholder deliberations as a practical implementation step suitable for existing regulatory programs. The approach employed watershed hydrology as a surrogate to set quantifiable implementation targets for aquatic life impairment that is subject to multiple known and unknown stressors. The approach, using hydrology as surrogate, proved to be effective in managing watersheds that are faced with urbanization impacts but at the same time are bounded by limited data and technical capabilities. Instead of going through the traditional tedious and expensive processes of data collection, analysis, model development, and control measure assessment, this new planning approach provided a simple yet reliable alternative for effective watershed management. The power of the approach was fully utilized through the new management framework, in which the scientific findings successfully supported informed decision making that involved all stakeholders. More importantly, the water quality data and the hydrological information recently presented revealed that the environmental quality is improving due to the application of the plans developed through the implementation of the framework. It would be reasonable to expect that to reverse the negative impacts of actions which occurred for over a fifty year period would require a long time to implement needed actions and that a positive response in the river might require even more time. However, in the Shawsheen over a relatively short 10 year period, the observed progress on implementing actions in the watershed and the river's response is promising.

In summary, the process applied in the Shawsheen was consistent with the new management framework by including the three major elements and the necessary set of conditions to address water resource issues at the watershed level. A detailed investigation of the systematic step by step problem solving process used to address the three water resource issues revealed that this interdisciplinary approach was not only successful in bringing external resources to the process for addressing local issues but was also successful at improving environmental quality. The success in the Shawsheen is a result of the structure (common platform; partnership, and facilitation) and process (e.g., annual and 5 year planning) that provided the necessary organizational capacity to support the function of addressing local watershed issues through a set of systematic steps in which science played a key role in advancing a sound and well-informed decision making process.

7.1.3 Enhanced Management Framework

The third and final objective of this research is to further enhance the framework with lessons learned from its application in the Shawsheen. That is to produce a self-sustaining institutional structure for interdisciplinary decision making at the watershed level (policy). More specifically to make further refinements based on real-world lessons learned from an actual application (practice) of the new management framework. The refined management framework (policy), Grass-root Watershed Management (GWAM) Model, is intended to serve as a generic institutional model for holistic urbanization impact mitigation. Therefore, an analysis was done to link the theoretical management framework into a policy tool using the lessons learned and practical knowledge gained in the Shawsheen application. The lessons learned related primarily to capacity building at the watershed level and thus, the framework was refined accordingly to enhance organizational and functional capacities by providing the necessary mechanisms to sustain these capacities at the watershed level.

The Shawsheen application verifies that government policies, programs, and regulations and funding (external resources) should be appropriately integrated with local knowledge and input (based on watershed issues) for successful establishment of the **structure** of the framework.

- Common **platform** (or an establishment) to convene,
- Committed **partnership** from at least two major groups of the stakeholders, governmental and non-governmental organizations/watershed groups, and
- Effective **facilitation** of sustainable and interdisciplinary watershed management.

Also, it was learned that the **process** established through short-term (annual) and long-term (5 year) planning helped to bring external resources that were needed for accomplishing sustainable watershed management at the Shawsheen. Therefore, it was concluded to be essential that the

GWAM Model establish an appropriate organization (structure and process) to effectively conduct the function of addressing watershed issues by having the capacity to obtain and direct the use of external resources as needed to sustain the process.

When developing a model, whether it is to simulate a physical process or an institutional process, it is important to clearly understand the necessary conditions within which the model can be applied. One way to enhance our knowledge and to keep improving a process and its underlying necessary conditions is through real-world based applications and assessments. As such, while it was confirmed that the Shawsheen met the necessary conditions as formulated in the theoretical framework, the lessons learned from the Shawsheen provided valuable insights and identified additional necessary conditions as follows:

- Full-time Team Leader
- Co-leadership by NGO
- Committees
- Funding from both government and NGOs
- Network and External Assistance

The functional capacity of GWAM should have two major features: 1) To address the issue through a set of systematic steps of decision making: and 2) The mechanism to sustain the decision-making process. The steps could be as simple as the four steps; problem identification, problem recognition, problem investigation for implementation planning, and problem solving through implementing actions. However, the key point is that the set of steps being used should be designed to help facilitate the process of addressing the issues over time while adapting to new information being gathered through data collection, scientific studies and the experience shared by members. Additionally, this process required integrating related regulations, programs, resources and stakeholder participation into the decision making at every step. While each step represents an individual phase of solving identified issues, the regular meetings provide the context for linking various inter-related project component together and the opportunities for well-informed deliberations needed to advance the decision-making process. Although the systematic steps used in the Shawsheen can be viewed as general guidance for addressing urbanization related water resource issues, each situation should be evaluated to identify the appropriate steps needed to effectively water resource goals. Some issues and locations may require more or less steps. As investigated and revealed in the Shawsheen watershed process, science played a key role in keeping differently motivated stakeholders engaged and participating in the deliberative process. The science was used to advance knowledge among stakeholders and was especially valuable for helping to resolve the conflicts and confusions among stakeholders. The integration of science was instrumental in the facilitation process that led stakeholders to overcome differences and make well informed and educated decisions. More specifically, the integration of scientific data collection, modeling analysis, TMDL development, innovative tools, and gap analyses was the essential ingredient needed to help a diverse group of stakeholders move beyond their initial opinions, doubts and limited understandings to a place of well-informed common knowledge and understanding. However, the Shawsheen process also illustrates the importance of using science wisely to support the process of reaching well informed decision making among a diverse group of stakeholders. Extra care is warranted to make sure that the scientific support not overwhelm local stakeholders as has been indicated as a limitation in the literature review of top-down approaches. As such, the request for scientific support should come from a deliberative process involving the stakeholder group from the bottom rather than from a state or federal government agency, especially when a decision requires local support. However, regular updates on scientific development or training as a part of capacity development could be originated from the government.

In summary, the enhanced management framework of the GWAM Model has organizational capacity and functional capacity. The organizational capacity consists of a structure (three elements), a process (long and short-term planning), and a set of necessary conditions to conduct the function of addressing urbanization issues through an interdisciplinary approach in a self-sustaining structure. The functional capacity includes a set of systematic steps that integrates science into decision making as an essential mechanism to sustain the process. The systematic steps identified in the GWAM model are problem identification, problem recognition, problem investigation for implementation planning, and problem solving through implementing actions.

7.2 DISCUSSION AND RECOMMENDATIONS

Urbanization occurs as a result of human driven societal demands and economic forces. It is realistically unavoidable and unstoppable. Empirical evidence clearly shows that urbanization that has failed to consider and address environmental impacts has resulted in extensive environmental destruction including degradation of water resources that are essential for human life. Appropriately balancing human's socio-economic goals with the environmental goals especially related to the sustainable management of water resources is emerging as a high-priority goal in today's society. Over 40 years ago in 1977, the UN Conference on Human Environment called for achieving the right balance between human activities and the environmental consequences. In 1992, the, UN Conference on Environment and Development emphasized the failure of over centralization of water management and called for replacing it with locally responsive systems at the watershed level. More recently in 2015, the UN adopted a resolution that includes several references to water governance, and stakeholder engagement. Despite the progressive understanding and recognition of the importance of managing water resources at the watershed level by engaging all watershed stakeholders, little progress has been made on developing an effective framework that engages local stakeholders in the decision making about local water resource management.

The major challenge is that we are attempting to address urbanization issues (involving bio-physical processes) in the watershed through a multi-dimensional management process involving physical, social, economic and cultural variations. The Integrated Water Resources Management (IWRM) points out that one of the challenges of success in watershed management efforts is related to stakeholder engagement. Specifically, IWRM indicates that accomplishing adequate stakeholder engagement in practice even when using well-intentioned and appropriate institutional systems is difficult because of limiting perspectives, experience and skills of government agencies and their overall lack of understanding of an effective process that would lead to success.

While pointing out the lack of knowledge in stakeholder engagement, especially on real-world evident based assessments, Organization for Economic Co-operation and Development (OECD) researched the stakeholder engagement process of several worldwide efforts and developed recommendations of necessary conditions for result-oriented stakeholder engagement. Most of the cases referred to in the OECD studies were focused on large scale water governance issues such as water demand, water scarcity, flood disaster management, policy reforms, and large scale dam projects. There are other targeted research efforts reported in the international literature that are pertinent for evaluating the elements of effective stakeholder engagement. For example, Koontz and Newig (2014) compared cases of the United States and Germany on collaborative watershed management in similar watersheds with predominantly agricultural use and Llobet et al., (2016) compared cases of the United States and Spain on governance for integrated water and flood risk management in similar urban set up. Although none of these efforts directly assessed stakeholder engagement in addressing urbanization-related issues, the knowledge acquired on effective stakeholder engagement in general from the literature is vital towards building institutional models designed for sustainable watershed management. Specifically, relevant published literature offers key information for building knowledge towards developing a multi-dimensional process with stakeholder engagement that adequately accounts for the numerous and inter-related environmental, social, economic and cultural factors involved with water resource management at the watershed level.

This research has resulted in the development of GWAM and thus, contributes towards expanding knowledge on how to effectively address the impacts of urbanization (a set of bio-physical processes), and provides a model framework to fully incorporates environmental and social dimensions into the process. The GWAM model represents the first hybrid model that has been specifically designed and field verified for mitigating urbanization impacts in watershed management at the watershed level. This generic model places emphasis on robust stakeholder engagement with interdisciplinary thinking at every step of decision making process. As part of this research, GWAM has been successfully applied and validated for comprehensive watershed management related to urbanization at the Shawsheen watershed, USA. As documented in this research, the application in the Shawsheen also advances knowledge in addressing urbanization impacts by using hydrology as surrogate for watershed management. Like many watershed modelling and analysis approaches, there is usually room for improvement and refinements based on future research findings. This research recognizes that this is also true for the Shawsheen's innovative hydrologic surrogate approach. However, it is important to note that team determined, through extensive stakeholder deliberation, that the approach produced results that were sufficient to support sound decision making that ultimately led to the implementation of watershed control actions and subsequent observed improvements in the Shawsheen River system. A perfect analytical solution to solving complex watershed issues is neither realistic nor necessary to make well informed management decisions. A thorough investigation into the Shawsheen case reveals that robust stakeholder participation and opportunities for thorough deliberations was an essential component for allowing the team to make continued progress with less than perfect information.

First and foremost, continuous development for more than 50 years, made the Shawsheen to reach a point where the stakeholders lives were directly impacted by flooding. In the meantime, the state government launched the statewide watershed initiative program by dividing the state into twenty seven watershed units, including Shawsheen watershed as one of them. Therefore, the success of GWAM attributes to, at least partially, a clear issue associated with urbanization which was flooding, for which the attention of the majority of the stakeholders existed, and the government's willingness or programmatic change towards stakeholder engagement also existed. As a result, GWAM was instrumental in bringing the external resources (through government programs) to successfully address the local issues with meaningful stakeholder engagement through an interdisciplinary decision making process. Another important aspect is that the context in which the new planning approach was successful. When there is no specific stressor (pollutant or other causes) which could be directly linked to the aquatic life impairment and the relative strength of each stressor was unknown, the new approach of using hydrology as surrogate became successful. It is important to validate GWAM and the new planning approach beyond the necessary conditions and context of which the success is validated.

While GWAM has been successfully validated through its application for the Shawsheen watershed, future research on GWAM could be expanded into to testing the model on more locations with differing characteristics and conditions. From a scientific process standpoint, the Shawsheen watershed serves as a typical watershed that experiences hydrological and ecological impacts resulting from urbanization. However, it's location in a developed country with generally favorable economic capabilities, high public awareness and where local advocacy can be strong are characteristics that are likely to be notably different than urbanizing watersheds in more developing countries where these characteristics could be very different. It would be very interesting to implement the GWAM model in a developing country and then compare the results to the Shawsheen example. It is expected that the geographical, political, and cultural settings may have different weights and may potentially lead to adjustments to the current GWAM model setup.

The scholarly literature that helped formulating GWAM came from a range of issues, water supply, agricultural runoff control, industrial pollution, urbanization, and others. Although GWAM focused on addressing the issues associated with urbanization, the fundamentals of GWAM such as bringing external resources to address local multi-disciplinary issues in a sustainable stakeholder driven problem solving process is still applicable for addressing other issues such as source water protection for drinking water supply, irrigation and farming related management issues. Therefore, another direction for future research on GWAM could be to use the model to address issues beyond land use changes and urbanization. While different problem domains may exist for these other issues, the fundamental mechanisms of integrating science, encouraging cooperation, and facilitating collaboration, as encompassed in the GWAM model, remain the same. It is expected that the GWAM model can help create new paradigms for solving issues in these areas.

A third area for future research on the GWAM model could be on the components themselves. In this research, different branches of physical science, hydrological, ecological, and biological sciences were integrated into the decision-making process for watershed planning and management. The research analyzed the motivational factors of the stakeholders and the process of effective communication and deliberation among differently motivated stakeholders as part of the step by step decision making process for solving urbanization issues. However social and psychological factors, such as command and control, authority, sharing power, education, economic status, race, language, etc. yet to be analyzed in depth. While it is true that scientific facts are inherently a powerful means for informing and convincing people, it could also be beneficial to investigate how different branches of social science can play a role in improving the facilitation among different groups. Exciting findings could be uncovered and further improvements to the GWAM model could be realized in this area as well.

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