1.0 An Anecdotal History of Stormwater Planning and Management

Early stormwater management planning and design focused on moving water (runoff) away from people, buildings, roads, and other infrastructure quickly. Design of “management” systems therefore created an hydraulically efficient drainage network consisting of direct connections from impervious areas to smooth pipes to discharge points in streams, rivers, lakes, and coastlines. Over time, the increased peak flows and volumes of discharges associated with urbanization degraded the physical structure of the receiving systems, evidenced by stream bank erosion and channel enlargement (among other impacts), compromised infrastructure with bank instability and scour around bridge abutments, and increased occurrences of flooding from smaller storm events. Hence, drainage design evolved to consider control of peak flows or quantity control.

Water quality impacts associated with urban stormwater runoff have taken longer to be recognized as a significant issue. Water quality control regulation in the United States initially focused on controlling pollutant discharges from point sources, such as industrial effluents. Unfortunately, successful regulations and requirements to treat point sources prior to discharge did not necessarily result in a corresponding improvement in the receiving waters. Officials had to look elsewhere, and eventually identified stormwater
runoff, or nonpoint source pollution, as a significant contributor to degradation of receiving water quality.

Today, stormwater planning and management in developed nations is largely driven by regulatory requirements. Communities, businesses, and individuals ideally want to exercise environmentally friendly practices; however, the reality is that environmental protection is expensive – whether to remedy existing problems or to prevent future problems. Hence, implementation of stormwater quantity and quality control practices is often required by law.

2.0 Stormwater Planning and Management Hierarchy

Typically, environmental regulation is initiated in relatively broad terms at a national level, which is then broken down into regional or state level, and final implementation at the local level (cities, counties, town governments). Figure 1 outlines the various levels of regulation or policy and agencies responsible for the enforcement, creation and implementation of policies in the United States and New Zealand. National policies or regulation are often written somewhat generic terms, recognizing that water-related issues will vary significantly according to geographic location, climate, land use patterns, etc. At each step in the regulatory process, proceeding from the national to regional to local level, requirements become more specific and perhaps more stringent. It is generally up to the regional authorities to define how to comply with or obtain objectives set out in national policies. At the local level, this usually means creation of district plans to manage development and its impact on waterways, defining capacity of publicly owned and operated drainage networks, and technical guidance documents for design, operation, and maintenance (hopefully!) of stormwater systems. Table 1 illustrates the functional relationships and responsibilities amongst stakeholders and local government departments within Auckland City. Information in the table was defined as part of a process to develop policy and technical guidance for local stormwater management.

While the details or specific objectives of each policy may vary according to location in developed countries, there are many common elements among policies and practices in place to achieve receiving water protection or remediation from stormwater impacts. Major comment components include some sort of permit to allow discharges of stormwater and/or adoption of a watershed approach to planning and management. The major policies in the United States and New Zealand (specifically applied to the Auckland Region) are highlighted in the following sections.
<table>
<thead>
<tr>
<th>Level</th>
<th>Regulations</th>
<th>Agency</th>
</tr>
</thead>
<tbody>
<tr>
<td>National or Federal</td>
<td>USA: Clean Water Act (CWA, 1972); Safe Drinking Water Act (SDWA)</td>
<td>US Environmental Protection Agency (US EPA)</td>
</tr>
<tr>
<td>State or Regional</td>
<td>USA: State regulations</td>
<td>State Departments of Environmental Quality (Virginia), Departments of Environmental Protection (New York), Departments of Conservation and Recreation (Virginia), Departments of Public Health (Colorado)</td>
</tr>
<tr>
<td></td>
<td>NZ: Regional Policy Statement, Regional Plans (Air, Land, and Water; Coastal), Codes of Practice</td>
<td>Regional Councils – Auckland Regional Council, Environment Canterbury, Environment Bay of Plenty, etc., consultation with Tangata Whenua, iwi</td>
</tr>
<tr>
<td>Local</td>
<td>USA: Development Plans, Drainage Manuals/Guides, Zoning Requirements, etc.</td>
<td>City, Town, or County Governments</td>
</tr>
<tr>
<td></td>
<td>NZ: District or City Plan, Drainage Manuals/Guides</td>
<td>Territorial Local Authorities (City Councils), consultation with iwi</td>
</tr>
</tbody>
</table>

Figure 1. General hierarchy of environmental regulation with impacts on stormwater planning and agencies responsible for oversight or administration in the USA and New Zealand.
Table 1. Stakeholders and Functional Relationships in Auckland City (Patterson and Menzies 2003).

<table>
<thead>
<tr>
<th>CUSTOMERS / RATEPAYERS</th>
<th>AUCKLAND CITY COUNCIL (ACC)</th>
<th>METROWATER (MW)</th>
<th>AUCKLAND REGIONAL COUNCIL (ARC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elected Councillors</td>
<td>Works Committee</td>
<td>Appointed Board</td>
<td>Regional Council Committee</td>
</tr>
<tr>
<td>Planning Committee</td>
<td>Utility Planning</td>
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<tr>
<td>City Planning</td>
<td>Auckland City Environments</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(ACE)</td>
<td>Water and Wastewater</td>
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<tr>
<td>Land Use Management</td>
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<tr>
<td>Policies / Plans:</td>
<td>Policies / Plans:</td>
<td>Policies / Plans:</td>
<td>Policies / Plans:</td>
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<tr>
<td>- District Plan</td>
<td>- District Plan</td>
<td>- Development &amp;</td>
<td>- Development &amp;</td>
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<tr>
<td>- Growth Forum</td>
<td>- Bylaws</td>
<td>- Connection Standards</td>
<td>- Connection Standards</td>
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<tr>
<td>- Development</td>
<td>- Standards</td>
<td>- Asset management</td>
<td>- Asset management</td>
</tr>
<tr>
<td>Guidelines</td>
<td>- Educational material</td>
<td>- Educational material</td>
<td>- Educational material</td>
</tr>
<tr>
<td>activities</td>
<td>- Activities</td>
<td>- Waters &amp; wastewater</td>
<td>- Waters &amp; wastewater</td>
</tr>
<tr>
<td>- Plan changes</td>
<td>- Plan changes</td>
<td>- Servicing &amp;</td>
<td>- Servicing &amp;</td>
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<tr>
<td>- Consultation on growth</td>
<td>- Consultation on growth</td>
<td>- development</td>
<td>- development</td>
</tr>
<tr>
<td>- Governance</td>
<td>- Governance</td>
<td>- Stewardship</td>
<td>- Stewardship</td>
</tr>
</tbody>
</table>

- **Auckland City Council (ACC):** Territorial Local Authority- Utility Planning; City Planning
- **Metrowater:** Council-controlled organisation for water and wastewater services
- **Auckland Regional Council (ARC)**: regional regulatory authority

2.1 United States

In the United States, the overriding legislation driving stormwater planning and protection of receiving waters is the 1972 Clean Water Act (CWA) and the Safe Drinking Water Act. With respect to stormwater management, the two major programs initiated from the CWA are the National Pollutant Discharge Elimination System (NPDES) and the Total Maximum Daily Load (TMDL) programs. Overall receiving water quality protection is addressed in the antidegradation policies of the CWA.

2.1.1 USA’s Permit Framework: The National Pollutant Discharge Elimination System (NPDES)

The NPDES framework initially targeted control of point sources of pollution, by requiring permits to discharge effluents to a receiving water. The 1987 amendments to

1 In New Zealand, regional councils may be considered the equivalent of state-level government in the United States, specifically with respect to development and growth strategy and environmental policy. City or town governments are called Territorial Local Authorities (TLAs) or simply, councils.
Section 402 of the CWA expanded the NPDES permit program to regulate NPS pollution, including stormwater discharges. Phase I of the program required a stormwater management program to be developed by:

- Owners and operators of municipal separate storm sewer systems (MS4s – typically cities, tribes, territories) serving populations greater than 100,000 people;
- Construction sites which disturbed greater than 5 acres (2 ha) of land; and,
- Most industrial activities.

In other words, localities with publicly owned stormwater drainage networks serving large populations had to determine a network-wide strategy for managing stormwater discharges. Likewise, construction or development projects that involved significant amounts of earth movement were required to develop and implement plans to control stormwater discharges during the construction phase as well as provide “permanent” stormwater management practices for long-term or on-going control of site runoff once construction was complete.

Phase II, promulgated in 1999, expanded coverage to include:

- MS4s serving populations greater than 10,000 people;
- Construction sites which disturb greater than 1 acre (0.4 ha); and,
- Generally the remaining industrial activities.

Lessons learned from the Phase I program inspired changes to permit requirements whereby for Phase II applicants, programs must include “six minimum measures” to address stormwater impact prevention and mitigation:

1. Public education and outreach
2. Public participation/involvement
3. Illicit discharge detection and elimination
4. Construction site runoff control
5. Post construction runoff control
6. Pollution prevention/good housekeeping.


The NPDES program is a technology-based program that relies heavily on the implementation of structural and non-structural best management practices (BMPs). A technology-based program recognizes that there is no one single “right” solution. A BMP approach acknowledges limitations of current practices, and allows room for improvement based on future research and development. For example, BMP performance is heavily dependent on system design and input characteristics, which may vary significantly from storm to storm and certainly amongst different sites. Most BMP characterizations quantify performance in terms of a mass reduction efficiency (if we’re lucky), whereby the success or failure of a system to treat stormwater is measured as a
percentage reduction of the incoming load, rather than its ability to reduce a pollutant concentration to a numerical standard. The wide variation in performance drives researchers and practitioners to continually collect monitoring data, and using that data, identify relationships between design and performance to ultimately develop better controls.

Design of stormwater BMPs is highly site specific, as often we try to “engineer natural systems” such as ponds and wetlands to control peak discharges to a specified level using known hydrologic and hydraulic relationships, as well as remove pollutants using mechanisms such as sedimentation or filtration. As the specific shape of a BMP may change dramatically from site to site, and performance is closely linked to BMP design, typically regional or local regulatory agencies will develop a design guide or manual for local practitioners. The assumption here is that design specifics consider local conditions, such as rainfall patterns, soils, pollutants of concern, etc. Care must be taken when referencing a manual of practice developed for one geographic region for use in another.

Additional information on the NPDES stormwater permitting program is available at http://cfpub.epa.gov/npdes/home.cfm?program_id=6. A valuable resource entitled “National Measures to Control Nonpoint Source Pollution from Urban Areas” is available at http://www.epa.gov/owow/nps/urbanmm/. In addition to describing sources and effects of urban runoff pollution, the manual presents scientifically sound techniques that are considered best practices. The guidance had also been compiled to help states to implement their nonpoint source control programs and municipalities to implement their Phase II Storm Water Permit Programs.

The widespread application of the Phase II regulations implies that a substantial amount of money will be spent on stormwater controls, including implementation, maintenance, and operation. The US EPA estimates that MS4s will spend US$9 per household per year for Phase II, whereas many cities regulated under Phase I actually spent US$45 per household per year (Armstrong, 2001). Other estimates suggest an annual cost of US$139,000 - $783,000 for a community of 100,000 (Luken and Swenson, 2001). The California Department of Transportation’s (CALTRANS) stormwater plan budgets US$250 million to fulfill permit requirements, including US$40 - $50 million for monitoring of BMPs (Kayhanian et al., 2001). By 2002, the Brevard County (Florida) Surface Water Improvement Program has implemented more than US$14 million in stormwater retrofits, and an additional US$14 million was dedicated for future projects (Stern, 2001).

2.1.2 USA’s Watershed Approach: The Total Maximum Daily Load Program

The Total Maximum Daily Load (TMDL) process was first introduced in Section 303 of the CWA in 1972, but has only recently (late 1990s) become a significant strategy for pollution mitigation and receiving water restoration. The program requires calculation of the maximum amount of a pollutant that a water body can receive and still meet local water quality standards. Standards are set by states, tribes, and territories in the United States based on scientific criteria. If a water body does not meet the set standard (often incorporating a numerical standard for a designated beneficial use), the water body becomes listed as “impaired” on a national register (“the 303(d) list”) and is therefore
subject to TMDL development. For more information on water quality standards, visit
http://www.epa.gov/waterscience/standards/.

From a technical perspective, a TMDL takes into account all of the sources of pollutant loads to a water body, and using modeling procedures, estimates the response of the receiving water. The “allowable” pollutant load the receiving water can accommodate and still meet water quality standards must consider pollutants from all inputs, including point and nonpoint sources of pollution. Hence, the evaluation of inputs must account for contributions from the entire watershed. The technical methodology is indicative of a watershed approach to planning and management.

The significant advance of the TMDL program is the integration of pollutant load plus receiving water response: or linking cause and effect. A TMDL is defined by equation (1):

\[ TMDL = LC = \sum WLA + \sum LA + MOS \]  

Where:
- TMDL = Total maximum daily load
- LC = Loading capacity
- WLA = Wasteload allocation (for point sources)
- LA = Load allocation (for nonpoint sources)
- MOS = Margin of safety

Development of a TMDL requires a significant investment of time and effort, including data collection, model development, calibration, and validation. An important component of equation (1) is the MOS term, which acknowledges uncertainties associated with modeling and data collection. A critical factor in TMDL development is therefore choosing the right model for particular watershed characteristics, understanding model components, limitations, and how to interpret the output.

Once the components of the TMDL are determined, a strategy must be developed for controlling discharges to meet the TMDL. As a watershed approach is used in the TMDL development, any number of solutions may be possible. The control strategy may include site-specific structural BMPs for stormwater treatment, additional controls on point sources, and nonstructural BMPs.

There are many other requirements within a TMDL process, but the focus here has been on some of the technical aspects. Additional information is available at http://www.epa.gov/owow/tmdl/. A more significant discussion of the watershed approach is presented in subsequent sections.

2.2 New Zealand
2.2.1 National Legislation

Requirements and regulation in New Zealand are more broadly defined at the national level under the Resource Management Act (RMA, 1991). The terms “stormwater management” or “nonpoint source pollution” are not specifically mentioned, yet the
Section 15 of the RMA requires controls for the discharge of “contaminants or water into water”. Regional councils are tasked with the responsibility of implementing programs and policies to achieve goals set out by the RMA; this is largely accomplished by setting out requirements for resource consents for activities which do not meet permitted activity criteria, such as new development or redevelopment that discharge to sensitive receiving environments. With respect to stormwater management, generally speaking, a resource consent may be considered similar to an NPDES nonpoint source discharge permit in the United States. If a development is deemed to have the potential to have adverse effects on a receiving system due to stormwater discharges, a resource consent to discharge stormwater must be obtained.

The consenting process is the mechanism by which BMP implementation is achieved on a regional basis. The process differs substantially from the NPDES program in that there lacks blanket applicability of requirements to obtain a consent, e.g., construction disturbing greater than XX hectares of land. Resource consents to discharge stormwater in New Zealand are considered on a case-by-case basis, although ultimately the treatment objectives are similar in terms of levels of quantity and quality control. Regional councils are tasked with setting requirements, reviewing, and processing resource consents.

2.2.2 Auckland Regional Approach

The Auckland Regional Council (ARC) has developed a Stormwater Action Plan entitled “A Coordinated Approach to Regional Stormwater Management and the Delivery of Improved Stormwater Quality Outcomes” (ARC 2005). The plan identifies and divides objectives into the following workstreams, which are being pursued at a regional level:

1. Integrated Catchment Management Plans (ICMPs)
   ICMPs adopt a watershed planning and management process focused on mitigating impacts and improving receiving water and habitat quality. Amongst other elements, the process includes consideration of land use planning and zoning – identifying areas acceptable for particular types of development over another (high density residential vs cluster housing, etc).

2. Regional Solutions (includes source control, best practice techniques and environmental understanding)
   The workstream includes staff with expertise in hydrology, water chemistry, and environmental science. It involves research components for evaluating BMPs and developing new technological approaches. Also included is promoting concepts such as low impact development, and identifying and addressing implementation (acceptance) issues.

3. Communication and Community Education
   Research shows that success of environmental programs largely depends on community participation/buy-in/support. Education of public is one aspect, stakeholder involvement is more specific.

4. Regional Capacity Building
New Zealand has an identified skills shortage across civil engineering, yet the Auckland Region is undergoing heavy development. The ARC recognizes that introducing or encouraging processes such as creating ICMPs might place an additional burden on the already understaffed TLAs. Therefore, ARC is working to identify specific skills needs, and how to fulfill those needs.

5. Alternative Funding Sources

Rates (taxes) aren’t going to cover all the expenses with respect to implementing stormwater planning or building infrastructure, and cannot simply be increased. For example, the on-going maintenance of BMPs represents significant costs to local governments, yet there is no mechanism by which to fund it. Research shows that the most common failure of BMPs is due to lack of maintenance.

The ARC takes a two-tiered approach to regional stormwater management by including a program to develop watershed management plans (ICMPs), while requiring BMP implantation in many cases on a site-by-site basis as a condition for obtaining a resource consent for stormwater discharges. The ARC compiles many technical publications to assist engineers in designing stormwater systems. Most publications are freely available online at [http://www.arc.govt.nz/arc/environment/water/publications/](http://www.arc.govt.nz/arc/environment/water/publications/). Examples include TP-10 Stormwater Treatment Devices Design Guide Manual; and TP-108 Guidelines for Stormwater Runoff Modeling in the Auckland Region.

The development of watershed management plans (integrated catchment management plans, ICMPs) in the Auckland region is not a statutory requirement, yet it is strongly encouraged by the ARC. As such, the ARC has set aside significant amounts of funding and several staff positions dedicated to assisting the territorial local authorities (local city councils) with ICMP development.

In the Auckland region, the Auckland Regional Council (ARC) policies are not always completely aligned with those of the territorial local authorities (TLA - local governments or councils). For example, most of the TLAs consider flooding to be the main concern, rather than water quality, which is the priority of the ARC. Significant efforts are being made to better align philosophies and practices for a consistent regional approach to environmental protection.

2.2.3 Auckland City (Local) Approach

The Auckland Region faces considerable growth pressures; yet land is severely limited due to geography, as the region lies on a relatively narrow isthmus. Typical development patterns in Auckland have resulted in periodic extensions of the urban limits – ultimately contributing to urban sprawl. Stormwater infrastructure has struggled to keep pace with development; nuisance flooding and combined sewer overflows are common.

In Auckland City, the TLA’s District Plan generally sets a 60% maximum impervious area for development, as city-wide drainage network modeling indicates an upper limit of capacity at this level. However, in an effort to accommodate the Regional Growth Strategy, Auckland City has implemented a program that allows for higher coverage of
impermeable surfaces if on-site stormwater management practices (OSM) are implemented for water quantity control only. The City has developed an OSM manual (http://www.aucklandcity.govt.nz/council/documents/onsite/default.asp) for design of a range of practices suitable to the space limited constraints of an urban setting. In other words, design guidance for land-intensive systems such as constructed wetlands or retention ponds are not included as implementation is infeasible in the targeted application.

There are 7 other TLAs within the Auckland Region. Each has their own set of priorities, technical guidance manuals, and procedures.

3.0 Site Specific Controls: BMP or Technology-Based Approach

3.1 Objectives

Regardless of what country in which your development is sought, two main objectives for stormwater impact mitigation and the mechanisms by which to achieve them are common:

*Water quantity control* (control of flooding and erosion-inducing velocities):

- Control the peak discharge from minor storm events (usually the 2-yr and 10-yr event) to prevent “nuisance” flooding and erosive velocities;
- Control the peak discharge from the major storm event (usually the 100-yr storm) to prevent property damage and loss of life.

*Water quality control* (mitigate levels of pollution carried by stormwater):

- Implement measures to reduce solids/sediments/TSS by 75%\(^2\);

As a significant fraction of other stormwater contaminants of concern may be adhered to particulate matter, water quality control requirements generally are written in terms of controlling some measure of particulate matter, whether it is written as TSS, “solids”, or “sediments”. If significant removal of particulate matter is achieved, then by default a fraction of other pollutants are also removed.

Where local water quality issues are well-understood, there may be requirements or at least motivation to implement measures to reduce levels of other pollutants, for example:

- Nutrients (nitrogen and phosphorus) in the Chesapeake Bay Watershed (USA);
- Trace metals (zinc and copper) in the Auckland Region;
- Gross pollutants (litter) in Cape Town.

3.2 Choosing the Right BMP

The factors listed above often contribute to design recommendations and BMP “menus”. Module 4 introduced us to a tool (WinSLAMM) to use in choosing the right BMP for a

\(^2\) Specific % reduction varies according to locality, but typical targets are 70-90% reduction of some measure of particulate matter carried in stormwater runoff.
particular site. In many cases, particularly for small(er) site development, sophisticated modeling will not be required in order to obtain a discharge permit. Often, local authorities provide a BMP “menu” which is tailored to local conditions from which the site engineer can choose. It should be noted that involving a modeling process, or at the very least considering how well a specific BMP might address site-specific issues is a worthwhile exercise for the responsible engineer, regardless of regulatory requirements. In any case, the utility of the WinSLAMM program, or other stormwater modeling package is expanded herein, as modeling is inherently a significant portion of the technical aspects involved in a watershed approach to stormwater management.

In order to achieve the goals of the stormwater management policies, understanding BMP capabilities and limitations is crucial. Past studies have usually included evaluation of structural BMPs in terms of a percentage reduction in pollutant concentration or mass loading, although methods vary since an industry standard does not yet exist.

If all that is known about a BMP’s performance is the percent pollution reduction capability, prior knowledge or modeling of particular site loading and characteristics may aid in the selection of the proper treatment technology for the site. While this type of analysis is suited for watershed planning process, it is time-consuming and hence becomes less useful in selecting a BMP to comply with a permit-type program. For example, the NPDES program differs from the TMDL regulations in that the permits focus on preventing degradation of receiving water quality in all areas, and not only in waters that are listed as impaired according to the TMDL 303(d) list. Water quality and habitat impacts occur because of loading conditions and the assimilative capacity of the ecosystem. The impacts cannot necessarily be predicted if the only information regarding BMP performance is in terms of a percent reduction in loading. Rather, to assess receiving water impacts, it is also important to evaluate the capability of a structural BMP to reduce NPS pollution to a particular concentration or loading (Clary et al., 2001; Strecker et al., 2001). For example, an 80% reduction of construction site runoff may be substantial and should not be overlooked; however, if the influent TSS load is 500 mg/L, the effluent is most likely still quite “dirty” compared to the predeveloped condition, and will still have a negative impact on the receiving water. A more purposeful BMP evaluation therefore also includes analysis of effluent concentrations and factors which effect the BMP’s ability to achieve a specific concentration.

Understanding BMP limitations in achieving a particular level of water quality becomes more important where numeric criteria are being established for stormwater discharges. The lack of adequate information puts the burden on the US EPA and on researchers for standardization of BMP reporting methods, as well as expanding the type of data reported, specifically characterization of effluent pollutant concentration and downstream habitat impacts.

According to the Phase II NPDES regulations, the US EPA was charged with providing a “BMP menu” in order to assist property developers and MS4s in selecting the proper BMPs for sites, and is found at http://cfpub.epa.gov/npdes/stormwater/menuofbmps/menu.cfm. Localities have followed suit to incorporate specific conditions within their regulatory jurisdiction. Development of menus has been complicated by a general data deficiency, compounded by
inconsistencies in the research and reporting process, which prevent application of data collected at one site to another (Clary et al., 2001; Calamita, 2001; Kayhanian, 2001; Urbonas, 1995). These issues also effect the TMDL development. In Florida, the Department of Environmental Protection must meet with other groups to determine acceptable extent and methods of data collection and analysis before beginning the TMDL process (Kaye, 2001). In response to the need for standardized data, the US EPA in conjunction with the American Society of Civil Engineers (ASCE) undertook development of a BMP database which could be used to consolidate information and allow for consistent evaluation of treatment technologies. In order for results of monitoring studies to be accepted into the database, researchers must follow strict guidelines for data collection and reporting. The International Stormwater BMP Database is freely available at [http://www.bmpdatabase.org](http://www.bmpdatabase.org).

Calls for more monitoring of BMPs is frequent in the field of water resources engineering. Presentations and discussions during professional society conferences, as well as publications in the *ASCE Journal of Water Resources Planning and Management*, *Engineering News Record*, and *Stormwater* ([http://www.stormh2o.com](http://www.stormh2o.com)) focus on the need for consistent data collection, reporting, and evaluation techniques. However, the call for information is in direct contrast with the difficulty of collecting valid and meaningful data. In conjunction with development of the International BMP Database, a comprehensive monitoring guidance manual which discusses every aspect of monitoring has been developed ([http://www.bmpdatabase.org/docs/Urban%20Stormwater%20BMP%20Performance%20Monitoring.pdf](http://www.bmpdatabase.org/docs/Urban%20Stormwater%20BMP%20Performance%20Monitoring.pdf)).

The Urban Stormwater BMP Performance Monitoring manual also discusses benefits and disadvantages of reporting methods and performance evaluation methods (for example, percent concentration removal or mass load reductions and statistical evaluation of data). Other local guidance manuals are being established, such as the CALTRANS Stormwater Monitoring Guidance Manual and Data Reporting Protocols (Kayhanian, 2001). The success of stormwater management programs regulations will be accelerated through improvements in and expansion of BMP monitoring and reporting techniques.

4.0 The Watershed Planning Process

As we observed in the risk assessment process in Module 5, in order to determine a strategy for protecting an ecological entity, it is imperative to consider all of the sources of stress to that entity and systematically evaluate alternative approaches to managing those stresses. The same thought process can be applied to restoration or protection of a receiving water.

While BMP implementation has been shown to be effective at reducing stormwater loads from a given site, the process does not ultimately consider how to achieve a specific effect to the receiving water. As was described in the TMDL section above, where restoration or protection of a receiving water is the goal, a more holistic approach linking causes and effects gives an opportunity for flexibility of solutions, and has been shown to lead to greater overall success. As a watershed is the geographic unit which physically encompasses all of the contributions to a receiving water (assuming that atmospheric
deposition is not a significant stressor), then it makes sense that a protection scheme is based on a watershed-wide assessment.

As such strong evidence supporting the effectiveness of a watershed-based approach is emerging, the US EPA has published a draft guide on how to compile a watershed management plan. The handbook, entitled “Handbook for Developing Watershed Plans to Protect and Restore our Waters” is available for free pdf download at [http://www.epa.gov/owow/nps/watershed_handbook/](http://www.epa.gov/owow/nps/watershed_handbook/). The handbook was developed in part to assist TMDL development, but it presents a comprehensive methodology for creating a watershed management plan.

The remainder of this module relies heavily on information presented in the handbook. Rather than re-state what has already been written, students should download the manual for their own use, as the assignment is to develop a watershed plan for a site of your choice. To try to address some of our download issues, for students in Cape Town, Dr Armitage already has an electronic copy of the file; for students in Auckland, the handbook is available on the S: drive under S:\CaRE\papers\ENVENG701\Module 6. You will immediately notice that the handbook is 400+ pages – don’t panic! It is written in an easy-to-read format, and only about half of each page is occupied by text. Pay close attention to the Table of Contents, as you may find that you do not need to read entire chapters. While it is important to be exposed to all of the components of the watershed planning process, you should focus on the technical sections. Chapter 2 provides a very helpful overview, with Make sure you read carefully Chapters 5-11.

Other manuals, guidelines, and resources are available and may be useful for this assignment, or in your professional career. The Center for Watershed Protection ([http://www.cwp.org](http://www.cwp.org)) has created a set of protocols for rapid assessments of watersheds and methods for management plan development, although not all publications are available for free. Some sample watershed plans are at [http://www.cwp.org/freeresources.htm](http://www.cwp.org/freeresources.htm). Other information may be found via the US EPA Office of Wetlands, Oceans, and Watersheds ([http://www.epa.gov/owow](http://www.epa.gov/owow)). The US EPA’s encouragement of adopting a watershed approach to management is evidenced through an array of technical support and financial assistance. For example, a Watershed Academy has been created ([http://www.epa.gov/owow/watershed/wacademy](http://www.epa.gov/owow/watershed/wacademy)) to provide training programs and information. The Targeted Watersheds Grant Program supports studies of coalition-based strategies for attaining water quality objectives ([http://www.epa.gov/owow/watershed/initiative/](http://www.epa.gov/owow/watershed/initiative/)). Grants are awarded on a competitive basis for typically 2-3 yr periods. Technical support for TMDL development includes choosing and using models, data analysis, BMP analysis (selection and placement), among other aspects. Programs and support can found through the Office of Wetlands, Oceans, and Watersheds link above, as well as via the Office of Research and Development pages within the US EPA’s website.

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3 Auckland students take note that many of the manuals referenced in the text have also been posted on the S: drive.
4.1 Components of Watershed Approach

According to the US EPA (2005):

*Experience over the past decade has shown that effective watershed management includes active participation from stakeholders, analysis and quantification of the specific causes and sources of water quality problems, identification of measurable water quality goals, and specific actions needed to solve those problems...*

*Watershed plans are a means to resolve and prevent water quality problems that result from both point source and nonpoint source problems... [W]atershed plans are intended to provide both an analytic framework to restore water quality in impaired waters and to protect water quality in other waters adversely affected or threatened by point source and nonpoint source pollution...*

*A watershed approach is a flexible framework for managing water resource quality and quantity within specified drainage areas, or watersheds. This approach includes stakeholder involvement and management actions supported by sound science and appropriate technology. The watershed planning process works within this framework by using a series of cooperative, iterative steps to characterize existing conditions, identify and prioritize problems, define management objectives, develop protection or remediation strategies, and implement and adapt selected actions as necessary. The outcomes of this process are documented or referenced in a watershed plan. A watershed plan is a strategy that provides assessment and management information for a geographically defined watershed, including the analyses, actions, participants, and resources related to developing and implementing the plan.*

Steps in the watershed planning process are outlined in Figure 2. The more technical aspects of a watershed plan are addressed in Steps 2 and 3 of the process, and discussed in Chapters 5-11 of the handbook.
### Steps in the Watershed Planning and Implementation Process

1. **Build Partnerships**
   - Identify key stakeholders
   - Identify issues of concern
   - Set preliminary goals
   - Develop indicators
   - Conduct public outreach

2. **Characterize the Watershed**
   - Gather existing data and create a watershed inventory
   - Identify data gaps and collect additional data if needed
   - Analyze data
   - Identify causes and sources of pollution that need to be controlled
   - Estimate pollutant loads

3. **Finalize Goals and Identify Solutions**
   - Set overall goals and management objectives
   - Develop indicators/targets
   - Determine load reductions needed
   - Identify critical areas
   - Develop management measures to achieve goals

4. **Design an Implementation Program**
   - Develop implementation schedule
   - Develop interim milestones to track implementation of management measures
   - Develop criteria to measure progress toward meeting watershed goals
   - Develop monitoring component
   - Develop information/education component
   - Develop evaluation process
   - Identify technical and financial assistance needed to implement plan
   - Assign responsibility for reviewing and revising the plan

5. **Implement Watershed Plan**
   - Implement management strategies
   - Conduct monitoring
   - Conduct information/education activities

6. **Measure Progress and Make Adjustments**
   - Review and evaluate information
   - Share results
   - Prepare annual work plans
   - Report back to stakeholders and others
   - Make adjustments to program

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**Characterization and Analysis Tools**
- GIS
- Statistical packages
- Monitoring
- Load calculations
- Model simulation tools
- Models
- Databases

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Figure 2. Steps in the Watershed Planning Process (US EPA 2005)
4.2 Technical Aspects – Watershed Modeling

The role of the engineer in developing a watershed plan typically comprises data collection and analysis; model development, calibration, verification, and interpretation of results; and use of the model to develop a strategy for reducing pollutant loads. Chapters 5-11 of the US EPA handbook should be referenced.

Model choice is a significant aspect in developing a watershed plan. Ultimately, a model’s utility is only as good as the input data, and the user’s ability to understand the processes involved. Factors to consider include (but are not limited to):

- Underlying assumptions – For example, are you using a model that was developed for agricultural areas on an urban environment?
- Data availability for calibration and verification; cost of obtaining data. Data is often available from government agencies, but additional data is often needed.
- Level of detail required to achieve objectives - Models vary in complexity from spreadsheet applications to sophisticated computer packages, and each type has appropriate applications. Comparisons for hydrologic schemes and watershed models are presented in Tables 2 and 3.
  - Hydrologic modeling procedures? Hydrology is the over-arching driver for stormwater impacts.
  - Pollutant simulations? Does the model use a lumped parameter approach, or does it simulate specific pathways and characteristics of key pollutants?
  - Continuous vs event-based simulation?
- Familiarity of the user – How long will it take you to become proficient? What is the cost?

Table 2. Level of Detail in Simulating Runoff (US EPA 2005)

<table>
<thead>
<tr>
<th>Level of Detail</th>
<th>Equation</th>
<th>Assumptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generalized</td>
<td>Percentage of rainfall that runs off the land into the water (rational method/regression of rainfall and runoff observations)</td>
<td>Simple relationship between rainfall and runoff. One factor represents the loss associated with evaporation and plant uptake. No special consideration of slope or soil characteristics. No consideration of soil moisture.</td>
</tr>
<tr>
<td>Mic-Level</td>
<td>CN</td>
<td>Simple relationship based on studies across the country. Varies depending on soil type, vegetation, and slope. Considers soil moisture (antecedent moisture condition). Does not consider variations in storm intensity; uses daily rainfall.</td>
</tr>
<tr>
<td>Detailed</td>
<td>Infiltration equation</td>
<td>Describes infiltration of water and evapotranspiration. Considers soil moisture and soil type, vegetation, and slope. Considers variations in storm intensity. Time step is typically hourly rainfall or less.</td>
</tr>
</tbody>
</table>

Note: CN = curve number.
General model types include (from US EPA 2005):

**Field scale.** Some applications are focused on small areas at the subbasin or smaller level. Field-scale modeling usually refers to geographic areas composed of one land use (e.g., a cornfield).

**Physically based models.** A physically based model includes a more detailed representation of fundamental processes such as infiltration. Applying physically based models requires extensive data and experience to set up and test the model. HSPF and SWAT both include physically based processes, although many simplifications are still used.

**Lumped model.** A model in which the physical characteristics for land units within a subwatershed unit are assumed to be homogeneous is referred to as a “lumped” model. Discrete land use areas within a subwatershed area are lumped into one group.

**Mechanistic model.** A mechanistic model attempts to quantitatively describe a phenomenon by its underlying causal mechanisms.

**Numerical model.** A numerical model approximates a solution of governing partial differential equations that describe a natural process. The approximation uses a numerical discretization of the space and time components of the system or process.

**Steady state model.** A steady state model is a mathematical model of fate and transport that uses constant values of input variables to predict constant values of receiving water quality concentrations. Steady state models are typically used to evaluate low-flow conditions.

**Dynamic model.** A dynamic model is a mathematical formulation describing the physical behavior of a system or a process and its temporal variability.
4.3 Compiling the Watershed Plan

While there is no set standard for writing a watershed plan, the ARC recommends the following sections (note that the headers also give another perspective on what should go into the plan, from an “activity” standpoint):

1. Introduction
   1.1 Local Territorial Authority Stormwater Strategy
   1.2 Catchment Management Objectives (Social, Economic, Ecological, Amenity, Cultural)
   1.3 Regulatory Framework and Planning Considerations (District Plan, Structure Plans, etc)

2. Catchment Description
   2.1 Soils
   2.2 Geology
   2.3 Topography
   2.4 Vegetation
   2.5 Climate
   2.6 Existing Land Use
   2.7 Existing Stormwater & Wastewater Systems (Utilities & Services)

3. Status of the Receiving Environment
   3.1 Description of the Receiving Environment
      3.1.1 Estuaries
      3.1.2 High Energy Environments
      3.1.3 Infiltration and Soakage Areas
      3.1.4 Freshwater Lakes
      3.1.5 Freshwater Streams and Rivers
   3.2 Classification of Urban Streams
      3.2.1 Public Health
      3.2.2 Flooding
      3.2.3 Hydrology
      3.2.4 Erosion Hazard
   3.3 Gross Pollution and Sedimentation (visual inspection/site knowledge)
   3.4 Aquatic Habitat Ecology
   3.5 Amenity Values
5.0 Comments

There is no set requirement to answer the question: What water bodies should be managed using a watershed approach versus a technology-based (BMP) permit type or other approach? In the USA, waters listed as impaired (i.e., do not need stated beneficial use) are required by law to have a TMDL developed. In the Auckland region, the ARC strongly encourages territorial local authorities to develop ICMPs for all waterways. In other areas, strong community support for protecting aquatic resources may lead to volunteer organizations or town governments to develop watershed management plans for waterways that may not currently be impaired, but are considered as valuable resources.

Another comment is warranted after Dr. Armitage’s visit to Auckland earlier this week. The processes, policies, and considerations generally described herein apply to situations in developed countries. Water management challenges facing developing countries may involve a very different set of priorities and values, resulting in a very different management approach. As responsible engineers, it is imperative that we always
consider the end-user of our solutions: what is applicable in one situation may not be in another.

6.0 Assignment

Again, it is stressed that students are to review the handbook for a full description of the watershed planning process. The discussion herein is by no means a comprehensive presentation – but there was no need to re-invent the wheel, as good publications are available for free!

For the watershed you used in Module 5, develop a watershed management plan, using steps 1-4 in the US EPA flow chart (Figure 1). The following bullet points are meant as a further guide or hints as to how your assignment will be evaluated:

- For step 1, it is adequate to identify the key stakeholders and issues of concern. What are the local and/or regional regulatory agencies that should be involved? How might views or values between stakeholders differ?
- Focus your efforts on the technical side of the watershed planning process, namely steps 2 & 3 in the flow chart (all bullet points in the chart for steps 2 & 3 should be addressed).
  - Define specific goals, such as attainment or maintenance of a designated use. What numeric criteria or other standard of water quality applies? How do your goals relate to objectives or requirements of your local or regional planning body?
  - Use WinSLAMM for the modeling portion. If actual monitoring data is available, you are expected to calibrate and verify your model. If monitoring data is not available, you may use literature or model-generated values, but please state your source(s). A discussion of limitations or uncertainty in results is warranted, especially where monitoring data is not available. Students in Auckland should make use of the ARC contaminant loading spreadsheet available from the ARC website at http://www.arc.govt.nz/fms/stormwater/ContaminantLoadModelAPR06.xls. All students are welcome to investigate the model and decide if it is appropriate or helpful for use at your site.
  - Consider feasibility of management measures. For example, most of Auckland is characterized by highly impervious clay soils, hence infiltration or soakage practices are not likely to be effective for volume control.
  - Consider both structural and nonstructural (source control) practices. Can you quantify the effectiveness of nonstructural measures such as education? Be very careful about proposing nonstructural measures such as impervious area limitations. For more information, refer to:

- Describe alternative management plans you considered and why a specific one was chosen.

- For step 4, focus on milestones, measurable goals, monitoring, and education components.

- Use the outline recommended by the ARC for writing your plan. Not all items may necessarily be included.

## 7.0 References


