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Rural Storm Water Management: Water Quality, Flood Avoidance and System Integrity*

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1 Introduction

Water is found everywhere on Earth and is one of the most basic and common substances. It is the only natural substance that exists in all three physical states: solid, liquid, and gas. While most water is found in the oceans there is constant exchange of water between the oceans, atmosphere, and land. These complex exchanges are described by the hydrologic cycle (Figure 1.)

This document focuses on precipitation and surface water flows to and in streams and rivers and the management of excess precipitation runoff to comply with the federal Clean Water Act (CWA).

1.1 Precipitation events

Rainfall and snowmelt runoff vary by location, duration, and intensity. Rainfall can be intercepted by vegetation (tree canopies, shrubs, and grasses) as well as infiltrating into the soil. The

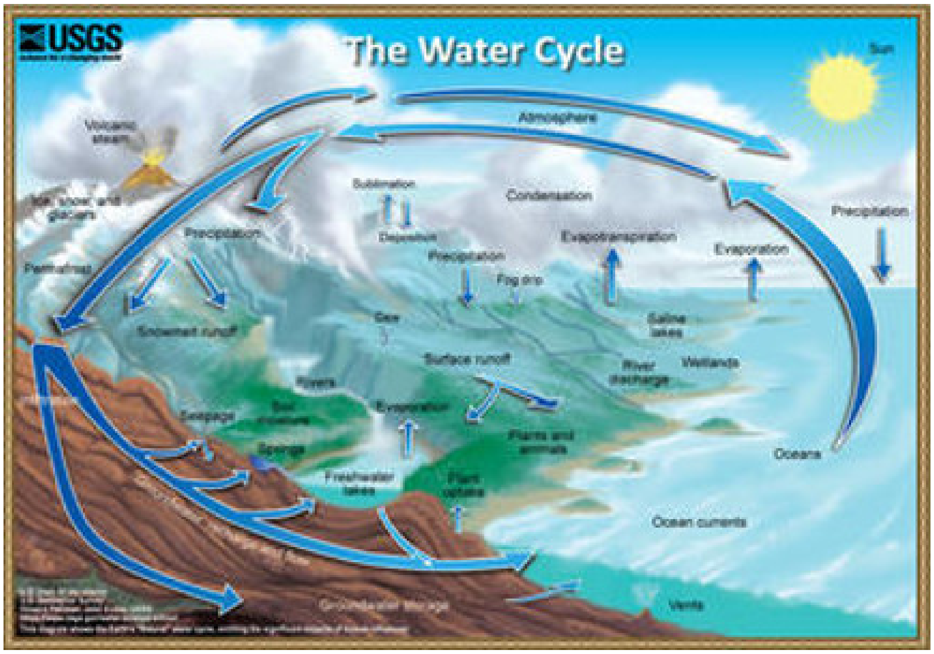

Figure 1: The hydrologic cycle.

amount not lost to interception is called *excess rainfall* which is what flows across the land surface to receiving waters in the basin's valley.

Storm intensity can vary from a gentle rain over a long period of time to very heavy rain in a short period of time. In the first case stream flow gradually increases, peaks later, and falls slowly as the storm passes. In the second case stream flow rapidly increases, peaks early, and falls at a rate relative to the amount and duration of the storm. Plotting discharge (or stage height) as a function of time is called a *hydrograph*.

Storm events vary greatly based on geography and climate. For example, in the temperate rain forests of northwest Oregon and Washington (particularly the coastal areas) frequent low intensity rainfalls can last for hours or days, primarily during the winter. In arid and semi-arid locations such as the Intermountain West and the Great Basin sudden high intensity/short duration storms in the summer produce flash floods that scour stream channels and carry large debris for long distances. Snow melt runoff in these areas can also be earlier in the year and more intense than in temperate regions.

Drainage basin shape and river network structure also affect the shape of the storm hydrograph (Figure2.)

All the above factors need to be included in storm water management plans; one-size-fits-all processes and designs will not achieve desired outcomes.

1.2 Storm waters

There are two components of storm waters of concern to regulators and the public: water quality and river network integrity. The former is the focus of most urban/suburban storm water

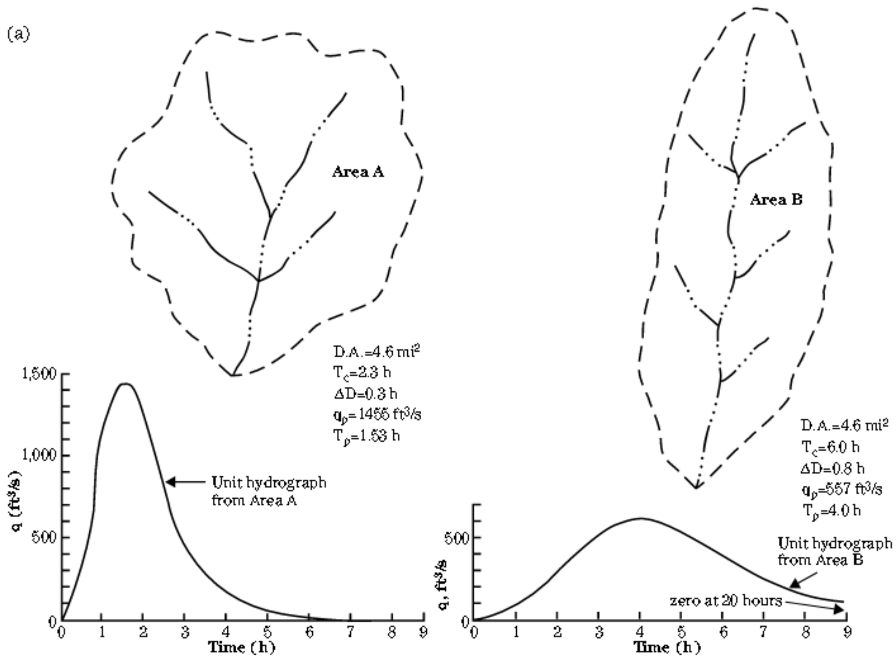

Figure 2: Storm hydrographs as affected by drainage basin shape and the river network structure. (From USDA Natural Resources Conservation Service National Engineering Handbook, Part 630 Hydrology, Chapter 16 Hydrographs.)

management regulations as most states require commercial and industrial operators to have discharge permits and Storm Water Pollution Prevention (or Control) Plans. Rural storm water management has water quantity of equal or greater concern because of the industries and residences dependent on sufficient potable water supplies. In rural areas storm water quality is becoming more important as water resources are limited by drought.

River network integrity is the second storm water component of concern. In urban/suburban areas (smaller drainage basins) channel scour, blocked culverts, and flooding can result from storm water discharges from point sources. In rural areas proposed projects might be required to re-route streams and storm drainage channels around the project area. In these cases it is necessary to ensure that the bypass channel be designed and constructed to emulate the energy dissipation and sediment transport capabilities of the reach it replaces. Failure to implement fluvial geomorphic factors will result in the failure of the bypass with flooding damage along its length as well as harmful alteration to downstream reaches.

1.3 Management approaches

Equations describing water flow in open channels (hydraulics) were developed by civil and environmental engineers and are the basis for storm water analyses. This approach works well in urban areas with the high percentage of impermeable surfaces and most commercial and industrial discharges from point source outfalls. The engineering-based management processes for urban and suburban areas (such as the SCS TR-55 Unit Hydrograph and the Santa Barbara

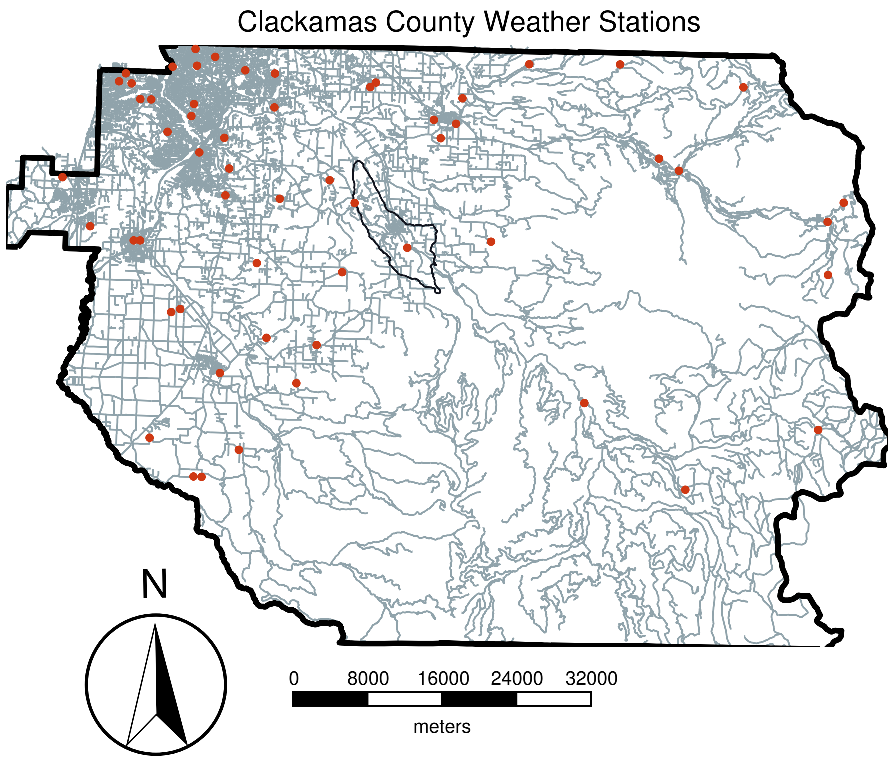

Figure 3: Weather stations in Clackamas County, Oregon (red dots; roads are in grey).

Urban Hydrograph) are successfully applied. However, this engineering approach to storm water management in rural areas and to entire river basins leads to flooding and other undesired results.

Effective rural and basin-wide storm water management are based on established principles of geomorphology, hydrology, and ecology so that control of excess precipitation (runoff) works with the receiving streams and rivers rather than against them. The engineering concepts of time of concentration, peak flow, and hydrographs of different storm intensities continue to be useful inputs but much more data are needed. Rural drainage basins have many ungauged streams and non-uniform spatial precipitation patterns and weather station locations; for example, Figure 3.

Understanding watersheds and the river networks that drain them has value beyond managing storm waters in rural areas so that industrial activities do not adversely impact the system downstream. This knowledge of river channel morphology, basin shape, hydrology, hydraulics, and sediment transport dynamics are also the foundation for restoring rivers and fish populations (from Lahonton cutthroat and Bull trout to Pacific salmon). With climate warming and water resources becoming more unpredictable while competing demands keep increasing an ecological/fluvial geomorphological basis for making operational, policy, and regulatory decisions becomes more important.

2 Storm water quality

2.1 Introduction

In the Federal Water Pollution Control Act (commonly called the Clean Water Act), as amended through P.L. 107–303, November 27, 2002, Congress set as its objective "to restore and maintain the chemical, physical, and biological integrity of the Nation's waters."

Storm waters enter receiving water bodies from either point source outfalls or surface flows. The two regulatory processes applied to discharge of storm waters by municipalities, commercial businesses, and industrial activities are NPDES[1] permits (general and individual) for point source discharges and TMDLs[2] for nonpoint source surface and subsurface discharges.

2.2 Urban areas

Urban area storm waters are collected by most municipalities in storm drains, treated, and discharged to receiving waters. Commercial and industrial permit holders discharge into storm drains (if available) or directly into receiving water bodies. Runoff from metal roofs or exposed machinery can carry leached metals such as zinc, oils, and other detritus such as dirt which need to be removed before the water is discharged from the facility. The primary constituents of concern are metals and organic compounds.

In suburban areas with small drainage basins industrial activities such as construction aggregate mines treat storm waters primarily by detaining them in settling basins, passing outflow through grassy swales or constructed wetlands, or retaining them for evaporation and slow infiltration into the ground. The primary constituent of concern is sediments.

In urban areas methods such as the process described in the Natural Resources Conservation Service[3] Technical Report TR-55 (Cronshey et al. 1986) are sufficient for regulatory compliance in most cases. Calculating detention/retention basin volumes using storm intensities of varying frequencies is a well defined process. Combined with sediment fences, wheel wash areas for vehicles, and flocculent treatments storm water management is relatively easy to implement.

States issue general and individual NPDES permits to discharge storm waters and require compliance monitoring at varying frequencies and discharge points.

2.3 Rural areas

Rural areas are highly complex and present many difficult challenges for operators and regulators. Industrial operations located in these areas include farming, ranching, logging, mining, and power generation/transmission. Regulatory concerns are for chemical contaminants entering receiving waters by surface sheet flows and maintaining stream integrity and function down slope from these activities. A major issue is when a stream needs to be re-routed around a project area.

[1] National Pollutant Discharge Elimination System
[2] Total Maximum Daily Loads
[3] NRCS; formerly the Soil Conservation Service, SCS.

The approach taken by regulators is to define a daily limit for input of a specific chemical constituent into the river network of an entire drainage basin. That daily limit is then apportioned by industry type or geographic location within the basin[4]. Unfortunately, in almost all cases no one in the regulated community finds the allocations acceptable. And the efficacy of the TMDL process in actually restoring and maintaining the chemical, physical, and biological integrity of the basin's waters is rarely, if ever, quantified because of the constraints of the current process. A major reason for these frustrations affecting regulators and the regulated public is the underlying perspective used to evaluate the drainage basin, river network, and the dynamics of the chemical constituent of concern when setting TMDLs and their allocations.

3 Managing nonpoint source storm waters

3.1 Introduction

Natural ecosystems have several characteristics that must be incorporated into data analyses, policies, regulations, and human operations. Some of these characteristics are:

- Environmental regulatory science is not based on experiments but on measurements and observations.
- All physical, chemical, and biological observation or measurement has a specific location and time associated with it that needs to be recorded.
- Restoration and maintenance of water quality, reduction of flooding potential, river network integrity, and fisheries are inter-related and based on the same two principles:
  - Understanding the environmental context of the area or project of interest.
  - Accepting that streams and rivers act to dissipate kinetic energy by minimizing the flows needed to transport sediments from headwaters to the basin outlet (Rosgen 1996).

3.2 Current approach

In 2001 the Water Science and Technology Board of the National Research Council (NRC) issued a report, "Assessing the TMDL Approach to Water Quality Management" (National Research Council 2001) prefaced their report by writing,

> "The Total Maximum Daily Load (TMDL) program, initiated in the 1972 Clean Water Act, recently emerged as a foundation for the nation's efforts to meet state water quality standards. A 'TMDL' refers to the total maximum daily load of a pollutant that achieves compliance with a water quality standard; the TMDL process refers to the plan to develop and implement the TMDL. Failure to meet water quality standards is a major concern nationwide; it is estimated that about 21,000 river segments, lakes, and estuaries have been identified by states as being in violation of one or more

[4]TMDLs include both point and nonpoint sources plus other factors. This document addresses how rural areas should be assessed and managed.

> standards. To address this problem, the U. S. Environmental Protection Agency (EPA) proposed an ambitious timetable for states to develop TMDL plans that will result in attainment of water quality standards. Given the reduction in pollutant loading from point sources such as sewage treatment plants over the last 30 years, the successful implementation of most TMDLs will require controlling nonpoint source pollution.
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> "These two features, the ambitious timetable and nonpoint source controls, are probably the two most controversial of many issues that have been raised by those who have questioned the TMDL program. Behind and intertwined with these basic policy issues are important questions concerning the adequacy of the science in support of TMDLs.
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> "The difficult challenges facing EPA and the states in the implementation of the TMDL program were immediately apparent to the committee. Because the committee faced a congressionally mandated deadline, a number of issues important to some stakeholders were not addressed comprehensively. These include bed sediment issues, atmospheric deposition, translating narrative standards into numeric criteria, and a full review of existing water quality models."

The NRC report noted that "[s]cientific uncertainty is a reality within all water quality programs, including the TMDL program, that cannot be entirely eliminated." This is a critical point that will be discussed in the 3.3 section. The report also discusses in detail the need for TMDLs (and storm water management systems) to be based on ambient water quality (also discussed in detail).

Changes recommended by the NRC report include:

- Development by states of appropriate use designations for waterbodies in advance of assessment and refine these use designations prior to TMDL development. Clean Water Act goals of fishable and swimmable waters are too broad to be operational as statements of designated uses.
- TMDL plans should employ adaptive implementation. Adaptive implementation is a cyclical process in which TMDL plans are periodically assessed for their achievement of water quality standards including designated uses. If the implementation of the TMDL plan is not achieving attainment of the designated use, scientific data and information should be used to revise the plan.
- The criterion used to measure whether the condition of a waterbody supports its designated use can be positioned at different points along the causal chain connecting stressors (such as land use activities) to biological responses in a waterbody.
- Biological criteria should be used in conjunction with physical and chemical criteria to determine whether a waterbody is meeting its designated use. In general, biological criteria are more closely related to the designated uses of waterbodies than are physical or chemical measurements. However, guiding management actions to achieve water quality goals based on biological criteria also depends on appropriate modeling efforts.
- All chemical criteria and some biological criteria should be defined in terms of magnitude, frequency, and duration.
- Water quality standards must be measurable by reasonably obtainable monitoring data.

In 2012 the US Forest Service published the first volume in its series, "National Best Management Practices for Water Quality Management on National Forest System Lands" (USFS 2012). Three objectives of the Forest Service are:

- Improve water quality to restore impaired waters on National Forest System (NFS) lands. These lands contain 3,126 CWA 303(d) listed waterbodies; nearly every Forest Service administrative unit (96 percent) has at least one impaired waterbody within its boundaries. BMPs identified in Total Maximum Daily Load restoration plans will improve water quality conditions in impaired waters.
- Improve the agency's ability to demonstrate results in watershed management.The Forest Service has made a commitment to implement several accountability tools, including a National BMP Program, to document improvements in watershed condition as a result of management and restoration actions.
- Improve the agency's ability to use adaptive management in land management plan implementation. The National BMP Program will provide a consistent, credible, and affordable agency-wide BMP monitoring program with coordinated data collection; monitoring information that can be aggregated at any scale; a database accessible to all Forest Service users; and reports that will be shared with EPA, States, and other partners. This type of monitoring program provides a continuous feedback loop for a successful adaptive management process.

Unfortunately, few if any substantive improvements to these deficiencies have been effectively implemented by the agencies in the past 19 years. While states might have storm water management programs with the same objectives implementation has not lessened the problems of effective compliance in restoring and maintaining the chemical, physical, and biological integrity of rural waters within their borders.

The following sections present a technically sound and legally defensible paradigm that fulfills the above criteria.

3.3 Natural ecosystem approach

Natural ecosystems are complex and trying to understand them is filled with uncertainties. Aquatic ecosystems in particular are highly variable and their response to precipitation events dependent on geomorphic, geologic, hydrologic, hydraulic, and biologic factors. Regulation of water quality at river basin (or river reach) scales is difficult and and uneven because of insufficient data for characterizing and understanding the spatial and temporal dynamics of these systems. Financial and other realistic constraints limit data availability. Data tend to be clustered around urban areas and other specific reaches and the time period for data collection is usually quite limited. Research agencies such as the US Geological Survey tend to have longer periods of data at gauge stations (not present on all sub-basins) and there might be chemical concentration data for some constituents. These conditions mean that applying mathematical differential equation models with fixed ecosystem functions fail to provide needed outcomes (Shepard 2016).

Replacing the fixed model approach to rural storm water management with one that works with the terrestrial and aquatic ecosystems and the human activities that occur on them is based on two broad concepts:

1. Use only available data and analyze those data using spatio-temporal statistical models that accommodate the uncertainties and variabilities of these data.
2. Analyze whole watersheds, or sub-basins, and work with the streams and rivers rather than against them.

3.3.1 Environmental data analyses

Environmental data differ greatly from the more familiar business, financial, and public data. Examples include: chemical concentrations cannot be below zero; toxics of concern tend to have very low values with occasional very high outliers; toxic concentrations frequently cannot be detected by the chemical laboratory's analytical methods; the familiar normal (bell shape) distribution of population values cannot be validly applied to geochemical concentrations nor is a geometric mean a valid estimate of expected value.

The statistics taught in science and business courses are those developed in the early decades of the twentieth-century by statisticians such as R.A. Fisher and Karl Popper for experiment-based agricultural yield improvement. The foundations of these statistics (including testing a null hypothesis which is never actually tested, replicate samples, a 95% probability that the results are not due to chance alone for acceptance of the null hypothesis, acceptance of the alternative hypothesis also without explicit testing when the null hypothesis is rejected) do work with business, financial, and public data (such as employment levels and GDP) but they fail to produce technically sound and legally defensible results when used with the spatially- and temporally-sparse, variable, and highly skewed data commonly found in geochemical samples or with biological data which are frequently counts (whole numbers). Environmental regulatory science is not done by experiments but by making observations and measurements. Therefore, different, and specialized, statistical models (which have been developed over the past few decades) are required.

Two major objectives for the analyses of environmental data (including storm water management, TMDLs, flood reduction or avoidance, and river/fisheries restoration) are forecasting (including concentrations in non-sampled locations), and measuring inherent natural variability. Understanding these objectives allows discharge permit holders, regulators, and policy makers make better informed decisions and can quantify the efficacy of regulatory actions.

3.3.2 Water quality

Too often rural water quality concerns focus on a single location and do not consider the watershed in which it is located. High nutrient levels in a stream adjacent to a farm or dairy are commonly assumed to be related to farm or dairy operations, but this assumption takes the measurements out of their environmental context. Before penalizing the operator for violating a maximum concentration limit regulators should consider all factors affecting water chemistry in that stream reach.

Among the factors affecting the measured concentration of a chemical constituent at a stream location are the season, flow velocity, riparian cover, soil composition and chemistry, upstream concentrations, and the beneficial uses of surface waters currently in that reach. Relevant factors include the adjacent agricultural operation obtaining potable water from wells, potentially affected aquatic organisms not present, downstream distance to a surface water use, and rate of dilution all contribute to an assessment of adverse affects.

Sediments from roads, aggregate material mines, slopes denuded of their normal vegetation by wildland fires, and construction sites are frequent concerns to regulators and the public. Whether the sediments actually adversely impact beneficial uses for that reach (commonly fish) is usually not considered by regulators, and fish species of concern may not occur in that reach. Looking at the watershed context when evaluating water quality greatly improves operational and regulatory decisions.

3.3.3 Flooding

Civilization developed along rivers. They supplied food, water for all uses, transportation routes, and fertile farm lands in the periodically flooded bottom lands. This trend continues but in urban and suburban areas in particular we have prevented river access to their flood plains by building levees, armoring banks with rip-rap, and channelizing to straighten the river's course or confining it to a concrete drain. This leads to more frequent and more severe flooding as the climate changes and human populations increase.

Storm water flood controls used for decades do not fit into the CWA's objectives and produce high economic costs. In many places a watershed approach can replace these older practices by restoring the natural rhythms of rivers and their sub-reaches . When done using developed knowledge of the watershed and river morphometry, geology, and precipitation history flood reduction and river/fisheries restoration can be simultaneously accomplished. The results comply with the CWA's objectives of restoring and maintaining the physical, chemical, and biological integrity of reaches and river systems.

4 Conclusions

As the climate continues to change it alters patterns of drought, wildland fires, and storms. Water resources are more limited and uncertain, particularly in semi-arid and arid environments. The concerns of operators, regulators, and society include: competing demands for limited water resources; toxic chemicals in potable water supplies, irrigation waters, and fish; and flooding of suburban residential developments, town and city centers, farmlands, and flood plain industrial activities. Past storm water management activities contributed to many of these problems. We must accept that the approach to storm water management needs to change to reduce the economic, environmental, and societal costs of harmful water quality, flooding, and smaller fish populations.

The tools have existed for a long time and there are only benefits to be gained by applying them. The environmental approach to storm water management, particularly in rural areas, uses proven fluvial geomorphological and ecological principles to allow streams and rivers improve themselves.

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