Urban Stream Impact Protocol

A methodology for assessing water quality and source determination

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URBAN STREAM IMPACT PROTOCOL: A GIS-BASED METHODOLOGY FOR ASSESSING WATER QUALITY AND SOURCE DETERMINATION

Andrew Lee and Jon Toonkel

I. PROJECT INTRODUCTION

Water quality testing is an ancient concept. Since the beginning of human civilization, our water sources have been examined for their potability (Collins, 34). Throughout United States history, laws have been passed to preserve and protect the accessibility, usage, and water quality of the waterways all over the country. The government has actively managed water as a public resource for 100 years; has created legislation that addresses water quality for 50 years; and has taken an active role in surface water quality monitoring, regulation, and enforcement for about 25 years.[1]

Waterways form a critical basis for regional identity and can be shaped by the land use and development in the area. The health of a stream or river correlates directly to human impacts and stresses applied to the region. Many people do not feel ownership or affinity to the watershed in which they live and might not have access to specific information that would shed light on the environmental state of their surroundings. Waterways provide recreation, beautiful scenery, and drinking water, therefore the health and quality of that water is vital to the health and safety of every person in every watershed. The Urban Stream Impact Protocol provides citizens with the tools they need to safely learn more about the water quality in their area in order to better understand the role water might play in their life. Ultimately, this tool should be helpful in changing the way in which water is understood, managed, and used.

Surface water quality testing has typically been undertaken by professional regulatory agencies at the local and state level, supported primarily by public funds. Only in the last decade have citizens begun to involve themselves in surface water quality analysis. While this rise in citizen participation is encouraging there are still many barriers, such as the scale and cost of monitoring that make the data collection process more difficult for interested individuals and community groups without many resources. The Urban Stream Impact Protocol is designed to further the potential of citizen involvement by providing techniques that cater specifically to people with varying experience and different amounts of funding.

Citizen monitoring projects can redefine human relationships to streams and waterways that have long suffered without interest or care. Testing of regional surface waters is expensive and time consuming for regulatory agencies, so citizen involvement may be the only way to enable comprehensive studies. Within Allegheny County alone there are 90.5 miles of rivers and 2024 miles of streams (Pinkham, 6). To sample this much water, we need strategy, tight protocols and effective quality control standards. The protocol utilizes an integrated systems approach to tie degraded water quality back to its topographical location. Through a combination of fieldwork and spatially referenced computer analysis, complex stream networks can be systematically analyzed. The user can then draw conclusions to the effects of land use and development on water quality.

Testing

Water quality testing is crucial in determining the environmental integrity of an area as well as the structural soundness of the surrounding infrastructure. Precluding water testing, sewer lines and treatment systems can be physically examined for points in the infrastructure that leak, need repair and/or regularly overflow. Visual observations can tell much about potential hazards and problems that might be present in an area, but this method is not as effective in pinpointing sources of pollution and contamination as testing the water quality itself. In order to test a waterway for pollutants, one must first locate proper points along the stream or river that will provide the most information. By conducting tests at the junctions in which streams meet a river, one can observe where the water quality is better or worse and at which point along the waterway the pollution source is located. Water in a stream or river can explain much about the land that it drains, and by repeating water quality testing at each junction, one can develop site-specific understanding of water quality its relationship to and land-use. Additionally, once a water quality baseline is created, it can be used at a later date to ascertain the relative success of infrastructure repair, improvement, and replacement.

GIS

To implement the Protocol the 3 Rivers 2nd Nature project team used GPS (Global Positioning System) and GIS (Geographic Information Systems), which are two technologies that have advanced the study of water and complex systems. GPS is an electronic device that triangulates orbiting satellites to precisely determine location and route (to an accuracy of a few feet). GIS is a computer program that visually places data in relationship to maps. GIS is organized so that information is layered on a map and multiple data layers can be immediately referenced in order to provide a better understanding of an area. The user sees data in a visual and geo-referenced format instead of reading it in a table isolated from its spatial location. Researchers, educators, planners, and recreational users all use this same system worldwide, allowing for the widespread sharing and collection of data.

Surface water as it descends to the ocean in a linear system: A drop of water falling upon a mountain during a rainstorm follows gravity; rain soaks into the ground and emerges as a spring, a spring follows a path, which becomes a stream channel. One stream meets another, and another, the channel gets larger until you find that you are at a river; follow the river, and you will find the sea.

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[1] For more than 100 years, the federal government has been passing laws to provide funding and oversight for the development of dams, reservoirs, and canals. Not until the 1940s and 1950s, however, did Congress begin to address water pollution legislatively. And initial efforts in this area, like the Federal Water Pollution Control Act of 1948, did not address pollution prevention plans or the development of water quality standards. Instead they focused on funding water treatment plants, identifying polluted bodies of water, and locating the polluters for legal action. Unfortunately, the strategy of determining which polluter caused which pollution was expensive and often unsuccessful (Texas Environmental Profiles, website).

The first water pollution legislation—the Federal Water Pollution Control Act of 1948—required states to locate these polluters, and billions of dollars of public money was spent, with little result (See Dzurick, Andrew. 1990. Water Resources Planning. Savage, Md.: Rowman and Littlefield, 56).

The Clean Water Act of 1972 forms the basis today for water quality protection for surface water in streams, rivers, and lakes as well as for groundwater. It was enacted as a series of amendments to the Federal Water Pollution Control Act of 1948, a law spurred by public concern over epidemics of disease caused by waterborne bacteria. The 1972 Act was prompted by the worsening state of U.S. rivers and by several high-profile oil spills, including the Santa Barbara channel spill, in which 250 million gallons of crude oil escaped to damage miles of California coastline.

II. THE PROTOCOL

As previously described, the biggest asset of GIS is its ability to combine multiple data sources in a spatial and intuitive way. This overlapping allows visual comparison that is critical in understanding complex relationships between factors. For the Urban Stream Impact Protocol, certain factors were selected that have a known affect on water quality, including slope, roads, land use, and outfalls (see section V. Watershed Layers). Raw statistical information and geospatial data for these features was obtained from various sources including the U.S. Geological Survey, U.S. Census, and the Allegheny County Sewer Authority (ALCOSAN). Using the geospatial analysis and statistical capabilities of GIS, data was processed into a usable format for visual analysis. Seven different map overlays were developed to provide specific insight on water quality. On each map, values were differentiated through color hues and line type. A consistent scale and vocabulary was maintained to allow cross-referencing between the overlays. By exporting the maps into a universally readable file format (PDF), users are able to view, print and exchange maps without GIS enabled software.

One of the most crucial elements of the Protocol is supplemental fieldwork. The process of collecting data onsite is what gives relevance to the study, and it is the foundation for a comprehensive and scientific approach to isolation of water quality impacts; therefore, taking a methodical approach to test site selection is crucial to make each study most effective. Because many parties with varying resources conduct water quality testing, a scalable protocol is necessary to optimize the time and monetary limits of each study. For example, some studies may allow for comprehensive watershed testing, while others may only focus on known impacted zones. Therefore, a priority of testing points must be selected in a three-step approach (first, second, and third level priority points), where the resolution and isolation of water quality impacts is refined with each subsequent step of point selection.

A fundamental benefit of the Urban Stream Impact Protocol is in its flexibility of application. Its scalable nature allows the user to vary the precision and scope of the water quality testing based on available time and resources. While accuracy is enhanced with each subsequent phase of the field study (first, second, and third level priority points), the general accuracy is directly related to the scale of the land area being studied.

Specifically, a smaller study of an individual watershed will yield great precision, while a study of a major river basin may require more phases of study and additional funding to reach the same accuracy in results. Therefore, the user must be conscious of the desired outcome and the relationship of study area scale to the results.

First Level Priority Points

The purpose of selecting “first level priority points” is to separate the stream or river into major zones. Working along the main leg of the stream, points are selected to assess the conditions at each connection of a secondary leg. This process isolates the major legs, or zones, and examines them for likely impact, while assessing how the conditions change along the main leg of the stream network. Any significant changes in water quality or known point-source pollutants along the main leg of the stream should be noted, as this will provide insight to potential sites for further study. In this first selection of points the number of test sites should be extremely limited, so as to quickly assess the most impacted zones of the watershed. The following are guidelines for selecting first priority points:

- Points should only be selected along the main leg, or highest stream order of the selected study area. (Stream order is a system of numbering streams based on sequence in tributary hierarchy (Black 425). Looking at figure 1 for example, the smaller tributary legs, labeled 1 and 2, feed the main trunk of the stream, labeled 3).

- Points should be selected directly downstream from all major splits or secondary legs of the stream network.

- Points should be selected both upstream and downstream from any site of known water quality impact, such as a sewer outfall.

Second Level Priority Points

The purpose of selecting “second level priority points” is to isolate specific legs of the stream network that indicate impacted conditions. Depending on the scale of the study, this level of testing may isolate water quality impacts to a specific source, such as an individual development or land use within the watershed. Consequently, a more comprehensive analysis of the watershed maps must be undertaken, focusing on the interrelationships between different layers. For instance, land use data and imperviousness should be compared to identify the locations with the most impact potential. Slope data should be compared to the building layer in order to identify the drainage paths of dense developments. Any number of combinations can yield potential impact zones that require testing points; it is up to the user to identify the significance of each comparison. Once tested, the combination of these selected points should be a fairly comprehensive water quality model for the watershed. The following are guidelines for selecting second priority points:

- Points should be selected directly upstream from all major splits or connections of secondary legs to the main leg of the system.

- Points should be selected both upstream and downstream from any known point source pollutants.

- Points should be selected both upstream and downstream from any specific areas that show significant impact potential.

- The selected number of points should be limited to those that aid in understanding water quality in secondary tributary legs above the point of confluence with the main trunk of the waterway.

Third Level Priority Points

The purpose of selecting third level priority points is to assess the amount of impact and to isolate the sources of water quality impact. These points should be very specific to each study, and should be selected based on the level of feasibility in time and monetary investment. These points can only be identified after the complete testing of second priority points, when known impacts have been recorded and isolated. Therefore, this level of priority is reserved for enhanced accuracy in point impact isolation, and should be specifically geo-referenced when collected. The following are guidelines for selecting third priority points:

- Points should be selected directly upstream and downstream from known sources of water quality impact, dependent on the testing of second level priority points.

- The selected number of points should be set with the intension of isolating and defining known areas of stream impact, mediated by the resources available for each study.

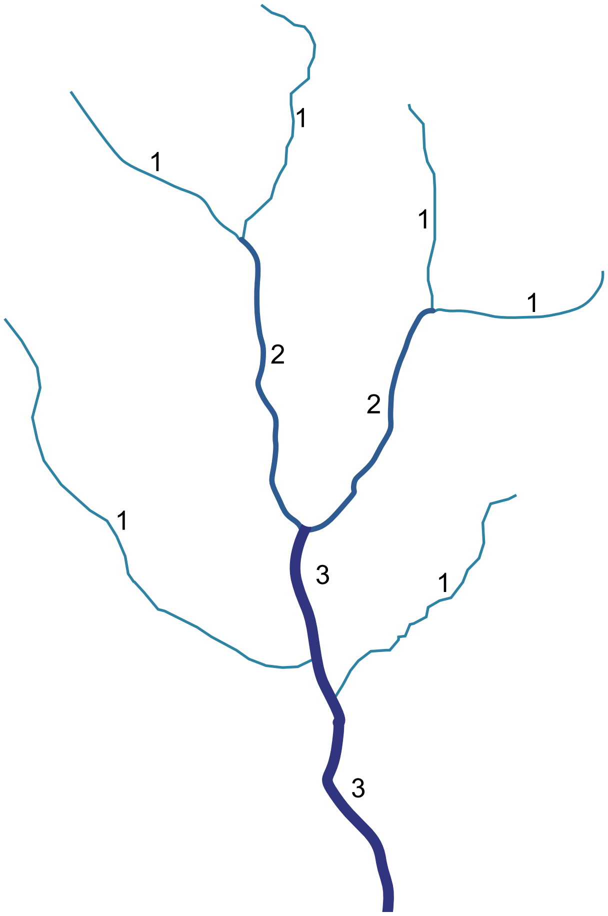

Fig. 1. Stream Order

III. WATERSHED LAYERS: ALLEGHENY COUNTY CASE STUDY

Slope

Data Source: Streams: Allegheny County GIS, 1995.
Watersheds: United States Geological Survey (USGS), 1997. Revised 3 Rivers, 2nd Nature (3R2N), 2003.
Slope: 3 Rivers, 2nd Nature (3R2N), 2003, based on United States Geological Survey Digital Elevation Model (DEM), 1979-2003.

This map depicts the ground terrain within the watershed, based on a Digital Elevation Model (DEM) of Allegheny County. Degrees of slope are directly related to color hues, where the darkest red is the steepest slope.

Slope is an important indicator for the physical dynamics of flow within a watershed. All natural flows of water follow the topography of the land, where gravity naturally takes water from higher elevations to lower elevations. The course that the water takes is called a drainage path, and such paths can be identified for the total area within a watershed. By examining slope data, drainage paths can be identified as the valley between two sloped areas. The major and secondary legs of the stream will naturally follow the deeper valleys, representing the perennial flow of the watershed. Perennial flows are those that occur indefinitely, present in both wet and dry conditions. These flows are important to note in order to understand constant flow patterns and how they are affected by adjacent impact zones. Similar ridges and valleys will identify non-perennial flows, those that are present only during wet conditions, which are typically periods of heavy rainfall. Though streams are not shown within these valleys, non-perennial paths are important in understanding the drainage of areas that exist away from the main flow of the stream. During wet conditions, these paths will dictate which areas contribute to the runoff into specific legs of the stream, and therefore identify the source of impact. By visually connecting the non-perennial drainage paths to the perennial drainage paths, a complete picture of the watershed drainage can be ascertained.

The one exception to drainage paths within a watershed is the installation of culverts. Though culverts are not specifically identified on the map, they are most likely to exist in areas where there is a break in the stream, but the slope data shows a continuation of the valley. Culverts are often installed where a stream corridor either cannot be supported, or may interfere with built infrastructure. Unfortunately, this is done at the expense of the stream habitat, and has impacts on water quality and quantity as well. An enclosed concrete pipe replaces a streambed along with its stones, soils, plants, and aquatic life. Lacking light, surface roughness, and natural filtration, these culverts present little opportunity for ecosystem functions that naturally improve water quality or the physical conditions that mitigate flow rates. The life in the stream is destroyed; therefore, in culverted sections of the stream it is important to examine the areas above the flow, where assessments can be made about potential impacts and water quality.

Land Use Resources
Data Source: United States Geological Survey/Environmental Protection Agency, 1992, Allegheny County GIS, 1992.

This map depicts the natural resources or "green" areas within the watershed, including areas of cultivated growth. This map is based on satellite land cover data, with specific land uses isolated as natural resources.

Identification of natural resources within the watershed is important in understanding the existing characteristics. Forested areas are the most typically "benign of all land uses" as they provide shade, pervious cover, and great potential for biodiversity (National Research Council, 88). Shade in low order streams is important in maintaining cool water temperatures, decreasing diurnal (night and day variance) and seasonal variability, and decreasing photosynthesis of plankton and aquatic vegetation (Forman, 215). Additionally, when forests are directly adjacent to the stream, flow conditions are stabilized due to natural filtration and the absence of impervious surfaces (Black, 308). Biodiversity is maintained through stable habitat conditions, and a layered variety of natural settings. All considered it is important to identify forested areas for their potential regenerative effects on water quality.

Cultivated growth, however, is a land use resource that represents a very unique condition. Like natural growth areas, it has very low impervious levels, which is beneficial for proper ground absorption and stable flow conditions. However, the use of fertilizers and pesticides presents a threat to water quality through the introduction of excessive levels of Nitrogen (N) and Phosphorous (P). This can cause significant limitations to aquatic life, in addition to the growth of algal blooms, which consume most of the oxygen in the water (Forman, 228).

"We cannot diagnose a stream's problems and prescribe an antidote without understanding what parts of the whole watershed are contributing to the problems" (Riley, 116).

Although some farmers have adopted responsible fertilizer use, larger cultivated areas will inevitably present some level of threat to water quality. This is also an issue of adjacency, where the closer the cultivated fields are to the stream, the greater the potential for impact.

Buildings

Data Source: Buildings: Allegheny County GIS, 1995.
Roads: U.S. Census Data, 1990.
County: U.S. Census Data, 1990.
Municipalities: U.S. Census Data, 1990.

This map depicts the actual development within the watershed, specifically the buildings, streets, and major roads. Municipal boundaries are included to aid in identifying the building clusters as a part of specific townships within Allegheny County.

This map provides important information as to the actual built conditions within the watershed. Whereas the land use data identifies the expected use and density of certain areas, this map shows the specific transportation corridors and built development. These characteristics of the building map provide crucial information about the relationship and orientation of human development to the stream system. Major transportation corridors are the most impacting infrastructures within a watershed. They contain significant amount of pollutants resulting from dense vehicular traffic. Salt used for road de-icing, oil, gas, and other auto residues are pollutants that dramatically affect habitat stability and water quality (Reimold, 129). Consequently, road adjacency and orientation present significant indication to the ability for these pollutants to reach the stream. Similar concerns are related to the density and adjacency of building footprints. Greater building density is an indication of increased human activity, resulting in a greater potential for pollutant loads from a larger population. Building adjacency determines whether or not humans have direct contact with the stream, with no buffer zone to protect the habitat.

Transportation corridors and building developments are both related to the patterns of development within a watershed. In examining this map, different patterns of development can be identified by the orientation of roads and buildings. Urban patterns of development are typically identified by the existence of orthogonal grids of roads and dense building lots, often regardless of geographical features and drainage paths. As a result, these urban zones often eliminate the natural buffer zones around stream corridors, creating significant potential for negative water quality impact and habitat destruction. Meandering roads and low-density building development identify suburban and rural patterns of development. Because an orthogonal grid does not bind these developments, there is often greater attention paid to geographical features and drainage paths. In situations where stream buffer zones exist in widths of at least twenty feet, significant potential exists for enhanced water quality and habitat stability (Ferguson, 8). These factors become specifically relevant in the relative position along the stream hierarchy, where smaller secondary legs of the stream are perhaps more sensitive to impacts than larger, main legs.

Land Use Infrastructure

Data Sources: Land Use: Allegheny County GIS, 1993.
Land Use - Industrial mining: United States Geological Survey, 1999.

This map depicts the infrastructure-based land uses within the watershed based on satellite land cover data. The five major categories of land use noted here are agriculture, commercial, residential, transportation, and industrial. Residential, commercial and industrial land uses are respectively grouped by color, with darker hues relating to density. Areas of Industrial-mining (locations of current or former mine activity) are highlighted due to its specifically high potential for stream impact.

Land use data serves as an important indicator for the character for each watershed by depicting the dominant functions and coverage areas. The overall coverage of infrastructure-based land uses will define whether or not the watershed is primarily developed or land with more natural growth. The coverage and density of specific land use types will dictate the typical conditions found within the watershed, whether they be housing developments or industrial landscapes. Waste management, water management and natural resource management are among the many defining characteristics of these land uses, and each presents a specific threat to water quality. Residential and agriculture, for instance, characteristically use excessive amounts of herbicides, pesticides, and fertilizer to maintain specific landscape conditions, ultimately leading to degradation of aquatic systems and water quality (Ferguson, 8). Commercial, transportation and industrial land uses, however, have a greater potential for increased pollutant loads from mechanical residue and heavy metals, in addition to significant impact from mine acid drainage. What all these factors have in common is their nature as undocumented, non-point source impacts. Though these sources are difficult to isolate, they are significant sources of impact, representing over seventy percent of all water pollution in the United States (Ferguson, 7). In order to fully understand the conditions in the stream system itself, it is crucial to first understand the conditions within the entire watershed boundary (Black, 359).

Development placement within the watershed boundary also plays a crucial role in impact potential. In some cases development may be concentrated around a specific leg or section of the watershed. Most likely, the impacts on the stream system will also be concentrated in this region. However, if development is dispersed there is a less clear indication of where the impacts will occur, and from which dominant source. It is also important to examine the stream corridor, or the areas directly adjacent to the stream flow. Buffer zones, or undisturbed areas around the stream, play crucial roles in allowing for natural filtration and habitat preservation (Black, 315). If certain legs of the stream have no buffer zone, there will be a greater potential for direct impacts from the specific land use to which it is adjacent.

Imperviousness

Data Source: 3 Rivers, 2nd Nature, 2003, based on Allegheny County GIS, 1993 and references.

This map depicts the impervious levels within a watershed based on values assigned to specific land cover types. The shaded areas represent the relative imperviousness of the ground cover, where 0% is a completely porous surface and 100% is a completely solid material.[3]

Impervious cover is an important indicator of potential impact, due to its multi-faceted effects on streams, including increased flow rates during wet weather conditions. When land is covered by impervious surfaces like roads and parking lots, water is forced to accumulate, and runs together across the surface. This is not a natural condition; rather water is usually directly absorbed into the ground (Black, 3). The result of this hard cover is a surge of runoff from these surfaces that eventually overload a stream, causing erosion, flooding, and the degradation of base flow (normal flow rate) conditions (Schueler, 2). Sensitive plant and amphibian habitats that depend on slow-moving pools and low, but consistent flow rates fall victim to extreme flow fluctuation, especially when exceeding eight inches in elevation per year (Schueler, 8). This effect is enhanced by the tendency for impervious surfaces to increase pollutant loads during wet conditions, specifically in the "first flush" runoff from a rainstorm (Ferguson, 8). Impervious surfaces such as parking lots have a tendency to collect and accumulate a series of pollutants, including auto residue, heavy metals, trash, and detergents (Schueler, 3). These surfaces can also have temperatures that are ten to twelve degrees higher than adjacent natural areas, presenting potential for temperature pollution (Schueler, 3). As rain falls on impervious surfaces, the temperature of the flow increases, and the residual pollutants are flushed into the stream. Only a few inches of soil are necessary to naturally filter and trap these pollutants, yet most often impervious surfaces divert flows into a storm sewer, which empty directly into a stream or river (Ferguson, 195).

While impervious cover has immense potential for impact on streams, it is important to understand the levels at which the impacts become severe. Natural land, or land with no development, typically has impervious levels around 0%. At this level there is potential for healthy stream habitat, aquatic life and plant diversity, and low fluctuation rates during wet-weather conditions. Degradation of these conditions, however, occurs at a very low ratio, typically around 10-15% impervious cover (Schueler, 3). At this ratio, there is a noticeable drop in channel stability and aquatic life diversity, and an increase in pollutant loads and flow fluctuation (Schueler, 8). To put this in terms of human population density, this is typical to areas with four or more individuals per acre (Schueler, 8). Beyond this ratio the stream will show signs of increased impact as a direct function of imperviousness, where plant and aquatic habitats are difficult or impossible to maintain (Schueler, 8). These ratios are typical of urban areas where flows are channeled into controlled drainage systems and the majority of land is covered by either parking lots or rooftops. Because this type of land cover cannot support healthy stream conditions, most restoration focuses on decreasing pollutant loads for the protection of downstream conditions (Schueler, 8).

Sewers/Outfalls

Data Sources: Sewers: 3 Rivers Wet Weather (3RWW), 2003.
Combined Sewer Outflows (CSO's), Outfalls, Treatment Plants: Allegheny County Sanitary Authority (ALCOSAN)[4], 2002/Dept. of Economic Development, 1999.
Toxic Release Points: Environmental Protection Agency, 1994.

This map shows documented and regulated point source releases, including combined sewer overflows, outfalls, treatment plants, and toxic release points. An underlay of the documented sewer lines within the watershed boundaries supplements this data.

Point source releases are important indicators of impact, because they exist as direct pollutant discharges into the stream system. Outfalls and combined sewer overflows represent significant potential for increased stream flow fluctuation during wet weather conditions, in addition to an increased pollutant load. Like many aging cities, Pittsburgh's storm water system is connected to the waste water system, resulting in the direct release of human waste into streams and rivers during overloaded conditions (wet weather). Human waste puts a pollutant load on a stream including excessive amounts nutrients, ammonia, and bacteria (Watershed Atlas, website). As a result, waterways are unsafe for humans to swim in, have inedible fish, and grow algal blooms that deoxidize the water (Gilbert, 266). Toxic release points exist as known sources of pollutants, presenting a range of threats to the chemical and biological stability of the stream. Although these specific points are typically documented, regulated, and monitored, their impacts on downstream areas are very seldom recorded or isolated. It is therefore important to note where in the stream

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[3] Impervious values are adapted from land use studies, including Capiella and Brown, assigning a specific impervious value to a specific land use (see table 1).

[4] ALCOSAN created a sewer map in response to impending legal action by the Environmental Protection Agency (EPA). The policy requires all sewer maps to be digitized in the near future. The survey is currently being completed on a municipality-by-municipality basis, and you will note the absence of certain locations from the Sewers/Outfalls dataset.

hierarchy these release points exist, so as to predict potential sites for impact.

The sewer underlay is included to account for the potential impacts of unrecorded point sources. Separated storm water systems are designed to capture runoff from impervious land cover, yet they will inevitably transport residual surface and ground pollutants generated from specific land uses (non-point sources). Combined sewers that mix wastewater with sewage present an additional impact potential with increased sewer density. Because of these factors, sewer leaks present a specific threat to stream quality through pollutant seepage from the sewers into the ground and stream water systems. Additionally, clean water that otherwise would drain into the stream will be captured by the sewer, resulting in more extreme flow fluctuations.

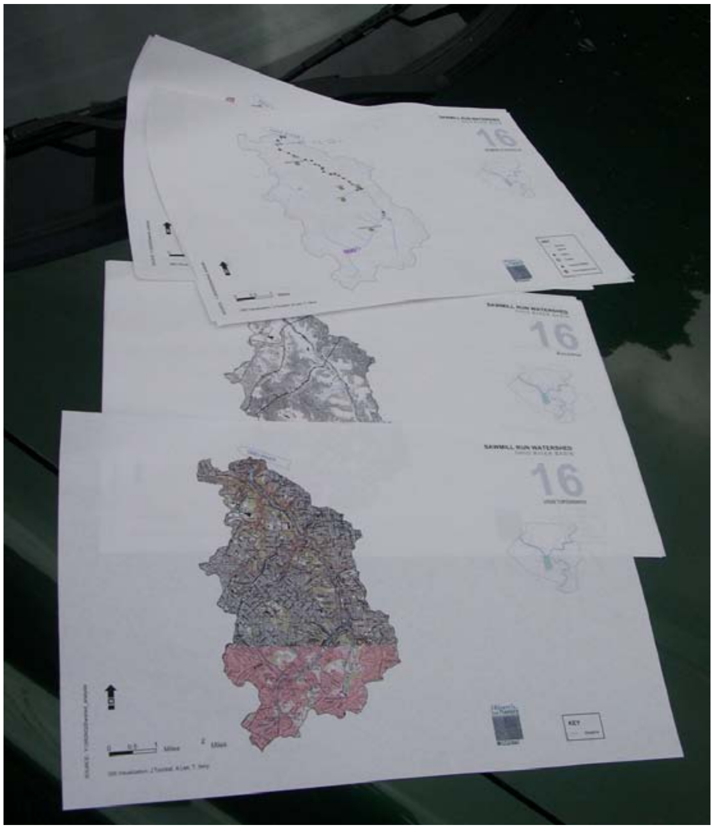
USGS Topo

Data Source: United States Geological Survey, 1992.

This map depicts the combined topography, transportation network, green cover and building footprints within the watershed. This map is based on United States Geological Survey data, using the standardized format of a typical USGS Quadrant Map.

Understanding and gaining access to sampling points on the watershed is a crucial element to the feasibility of field testing. This map combines several different criteria found in other maps, providing a general overview of the land characteristics. This specific type of map, a USGS Quadrant Map, is a format that is familiar to a wide range of users due to its extensive use in professional studies and recreational activities. Consequently, the user can quickly determine issues of access and orientation, and utilizes the map as a quick reference guide to the watershed. During water quality testing, landmarks and indications on this map can replace geo-referenced GPS points when resources cannot provide such technology. While this map may not provide insight to potential impact zones, its application as an orientation and referencing tool is equally as important for point selection.

IV. Sampling process: Allegheny County Case Study



Watershed Boundaries

In order to understand the hydrology of Allegheny County, one must know where the natural watershed and sub-watershed boundaries exist within the landscape. These boundaries represent the geographical edge where water drains to one stream or another. It is important to note that watersheds, or drainage basins, exist at multiple scales. A watershed can be as small as the area draining a small stream, or can exist as an entire river system. For the purpose of the study of Allegheny County, watersheds are defined at the scale of individual stream systems draining into the three rivers: the Ohio, Allegheny, and Monongahela. Watersheds are created by topography, defined by ridges, and drained by valleys, forming a continuous land area that contributes to a single stream flow.

The defined boundaries of a watershed are the fundamental basis of each stream's hydrology, yet these borders are somewhat hidden within the landscape. This necessitates the issue of orientation for the study of the Allegheny County watersheds. Because most citizens do not have access to detailed topographical and stream network data, several countywide maps were created to reference the watershed boundaries. The first and most relevant map of watershed boundaries is the *Streams* layer. This map shows the streams enclosed within each watershed, identifying both the legs that drain to the rivers, and the sub-legs that extend outward from them. The second map, *Municipalities*, shows the political boundaries that define the townships within the county. This map clearly shows the difference in methods of defining borders, and most importantly associates the widely known townships to their respective watershed boundaries. *Population Density* supplements this distinction, clarifying the most densely populated municipalities, and consequently referencing the urban core of Pittsburgh within these boundaries. The final map, *Major Roads* is used for orientation purposes: superimposing the known transportation corridors with the watershed boundaries to allow comparisons to be made. Together these maps provide the context for each watershed boundary, allowing the user to supplement the maps with their own undocumented knowledge of the site.

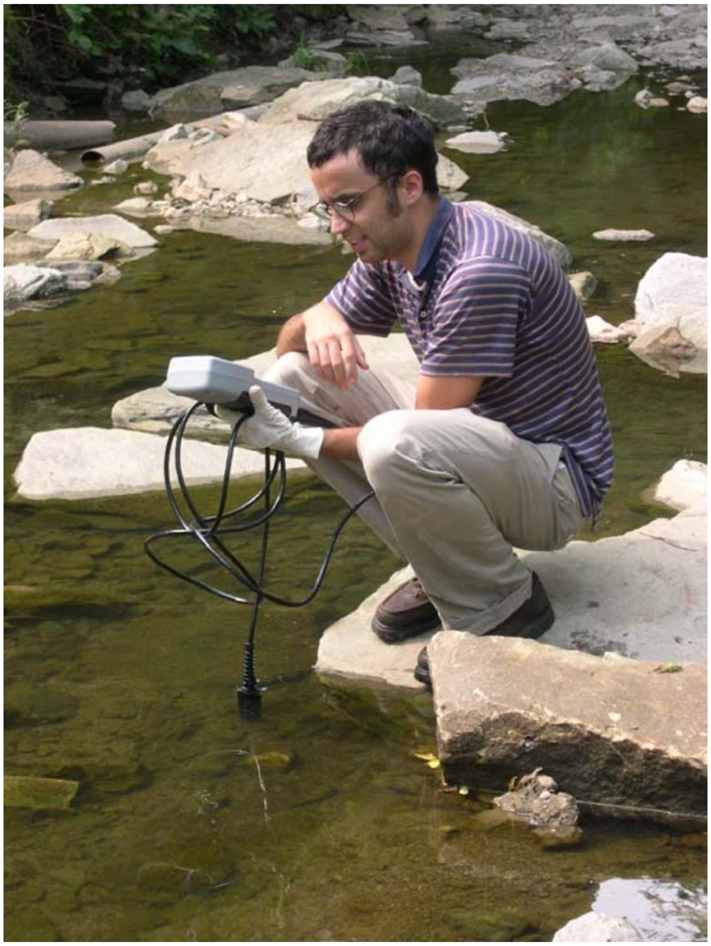
Protocol Implementation / Watershed Selection

Implementation of the Urban Stream Impact Protocol for the Allegheny County basin was tested through the sampling of nine watersheds. This method was used to test the effectiveness of the protocol on a diverse set of conditions, rather than focus solely on distressed watersheds. Consequently, priority watersheds were selected based on unique characteristics, rather than by impacted base flow conditions. This method focused the scope of implementation on the individual watershed scale, which was a feasible level of testing for the study. However, the Protocol has the potential to be replicated and used as an impact isolation study for the county, or the whole state.

Selection of priority watersheds in Allegheny County was based on three criteria that were found to be the most representative of unique conditions: stream order, development ratio, and watershed area. These three criteria depict the major natural and human conditions within the watershed. Decisions relating to natural conditions were based on stream order and watershed area, which together depict the potential diversity and magnitude of biological systems within the watershed boundaries. Decisions relating to basic human conditions were made based on development ratio, which gives the most general indication of the level of human impact through the magnitude of urbanization within the watershed. Together these three maps depict the character of each watershed, with the most extreme values representing unique conditions.

For each of the three criteria, a relative scale of numbers was assigned for each of the value groups (equally sized range of values for data spectrum). This was done to create a simplified method of selection where extreme values could be quickly identified, rather than constantly referring back to the actual values. The list of watersheds was compiled in a spreadsheet, listing river basin and map key, along with their respective relative values for stream order, development ratio, and watershed area (see table 2). Corresponding colors were added to the relative values, adding a visual aid to the selection framework.

Using this spreadsheet, nine watersheds were selected, based on an order of identifying unique conditions. As a prerequisite, watersheds were chosen only if they existed completely within the boundary of Allegheny County. This was done to maximize the implementation of the Protocol, where comprehensive county-based data was available. This narrowed the list from 56 to 45 watersheds.



V. SAMPLING MAPS: ALLEGHENY COUNTY CASE STUDY

Population density
Data Source: US Census Data, 2000.

This map depicts the population density in U.S. Census tracts for Allegheny County. The data is categorized into seven classes according to natural statistical breaks. The amount of people populating an area gives an indication to the stresses imposed on an ecosystem, specifically in surface water systems. Lawn care products, automobile runoff, and dense development patterns are several of the many side effects of population density that impact ecosystem stability. This map provides a clear indication as to which areas of Allegheny County are most densely populated, and the watersheds that are found therein.

Major Roads
Data Source: U.S. Census Data, 1990.

This map illustrates the major roads within Allegheny County—specifically highways and multi-lane transportation routes. These roads represent major circulation corridors within the region, highlighted by their radial connection to downtown Pittsburgh. Understanding the existence of these corridors provides a basis for identifying zones that are impacted by the heavy metals, automobile runoff, and increased drainage loads (storm water) associated with large roads. Careful study of where these major roads cut through specific watersheds will determine the level of impact associated with these negative effects.

Municipalities
Data Source: 3 Rivers Wet Weather (3RWW).

This map depicts the municipal boundaries within Allegheny County, which are political counterparts to the natural boundaries of the watersheds. The relationship between these two is often unapparent: municipalities are defined by population values and development patterns while watersheds are defined by geographical conditions. It is important, however, to compare the two to understand the political breakdowns found within each watershed boundary. Different municipalities within a watershed may have varying policies in land use, water resource management, and plumbing codes, yet all affect the same drainage path. Knowing the dynamics of these neighboring municipalities, and being able to reference them within natural boundaries, will yield a greater understanding of a watershed's character.

Watershed Area
Data Source: 3 Rivers 2nd Nature, 2003.

This map compares the relative land areas of all watersheds within Allegheny County, separated into six value groups. Observed here are the varying sizes of drainage basins, and how they represent different drainage capacities into the three rivers. Larger watersheds inevitably transfer more water at higher flow rates; they also have the potential for a more complex drainage network. Additionally, because larger watersheds inherently include more land area, they also have the potential to contain a greater diversity. A watershed with different landscape typologies results in a range of soils, plants, habitats, and wildlife in varying states of natural condition.

Stream Order
Data Source: 3 Rivers 2nd Nature, 2003 based on Streams: Allegheny County GIS, 1992.

This map classifies each of the Allegheny County watersheds depending on their relative stream order, or stream system complexity. These values are based on an analysis of perennial streams, or streams that exist during both wet and dry conditions. Stream order is a number assigned to the hierarchy of a stream, where the highest order is the main drainage leg and the lowest order includes the smallest sub-legs. Higher stream orders occur when two legs of similar order combine into a larger drainage path (see figure 1). By assessing these connecting paths, stream order is most often associated with stream complexity, which assumes a watershed with a higher stream order will contain a greater number of sub-legs and a more complex drainage structure. It is often seen that watersheds with a higher stream order will have greater area with more diverse conditions, and in turn a greater potential for biodiversity. It is also important to note the difference in human impact potential between lower and higher ordered streams. Lower ordered streams are often small, accessible at the bank and have fragile natural conditions, while streams with higher orders are often larger and less accessible, with a greater potential to dilute pollutants.

Development

Data Source: 3 Rivers 2nd Nature, 2003 based on Land Use, Allegheny County GIS, 1993.

This map depicts the ratio of developed (zoned) land area to the total land area for each of the watersheds within Allegheny County. This ratio includes specific types of development by zoned land area, not actual buildings.[2] On the county scale, this map clearly identifies the densest areas of development and characterizes the watersheds on a scale from urban to rural/natural. Although no specific impact zones can be isolated from this data, there is an assumed potential for greater human impact associated with highly urban watersheds, where issues of imperviousness and wastewater management supersede efforts for stream preservation.

Coal Seam

Data Source: Pennsylvania Department of Environmental Protection.

This map, based on USGS Coal Seam data, depicts regions within the Allegheny County area that have either surface or subterranean coal deposits. Because Allegheny County has a history of high industrial activity and resource extraction, this coal seam data can serve as an indicator for areas that were potentially mined. Although current mining practices are monitored and recorded, abandoned mines that are undocumented represent a significant impact potential on watersheds through acid mine drainage (heavily acidic water that drains from mines).

ALCOSAN Coverage

Data Source: Allegheny County Sanitary Authority (ALCOSAN), 2003.

This map depicts the outfalls and sewer lines within the precinct of the Allegheny County Sanitary Authority (ALCOSAN), which is the primary governing body for wastewater management within the Allegheny region. This coverage area defines the limits of the data used for the study, specifically for known outfalls/releases and sewer lines. Outside this boundary, data collected on outfalls and wastewater management systems is done

"What occurs in the stream cannot be considered independently of what occurs on the watershed. That is the fundamental precept of watershed hydrology. Civilization's water management practices have, for too long, ignored that simple fact" (Black, 359).

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[2] Land cover data values of residential, commercial, and industrial were assumed to be development. Where land cover data was unavailable (i.e. outside Allegheny County, but inside the watershed boundaries), the total watershed area was readjusted to exclude the unknown areas.

VI. CONCLUSION

The Urban Stream Impact Protocol empowers citizens, allowing them to make educated decisions for their waterways without relying on governing bodies for data collection. The community now has a scientific approach to diagnose water quality problems and to find sources of impact. This system is a tool that can be used by citizens with varying degrees of resources, expertise, and interests at a range of sub-watershed and watershed scales.

The Protocol provides GIS maps of the fifty-six streams of Allegheny County, displaying a variety of factors that very closely affect the quality of water. This data and information is made accessible so that any variety of people can utilize these maps to examine the health and quality of their surroundings without necessarily having access to the computer software. These maps, combined with the methodical approach to test site selection defined by the Protocol, provide the resources to allow any citizen to take the initiative of assessing the quality of their watershed in a meaningful way.

Water affects the life of every being and the Protocol intends to accentuate the relationship by giving people the tools to explore and discover what is unique, beautiful and potentially harmful about the water in their life. Citizens are able to draw their own conclusions about the conditions of their watershed. In addition, data distribution increases public awareness of water quality conditions and establish community participation in the process of impact isolation. Armed with a systematic sampling methodology, communities have the potential to solicit positive change, and reclaim local waterways.

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