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RAMANESSIN BROOK
NONPOINT SOURCE POLLUTION SOURCE ASSESSMENT
AND
STORMWATER IMPACT STUDY

DECEMBER 2005

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Executive Summary

Building on important research conducted by the Monmouth County Health Department, the Ramanessin Brook Nonpoint Source (NPS) Pollution Source Assessment project serves to define the link between glauconitic soils and the fecal coliform and total phosphorus impairments that have caused the Ramanessin Brook to be designated by New Jersey Department of Environmental Protection (NJDEP) as impaired in its Integrated List of Waterbodies (NJDEP, 2004). The project was proposed to the NJDEP Division of Watershed Management's 319h nonpoint source pollution mitigation grant program in September of 2002. A grant was awarded to the Monmouth County Planning Board in the summer of 2003, and the project was initiated in October of 2003 as a partnership among Monmouth County Planning Board, Navesink – Swimming River Group, and TRC Omni Environmental Corporation (TRC Omni).

TRC Omni collected and reviewed existing information, and built upon the findings of the initial study that found that properties of glauconitic soils cause phosphorus to adsorb to sediments and may create a sustainable habitat for fecal coliform bacteria. With increased flows and velocities from stormwater plaguing the Ramanessin Brook, this project was planned to better understand the degree to which erosion of glauconitic sediments in the stream channel causes the high concentrations that impair the waterway. To determine baseline water quality in the watershed, water quality sampling and analyses were performed. A total of five stream sampling station locations were sampled bi-weekly from July 2004 to June 2005, and one background station was sampled six times from July 2004 to October 2004. These samples were analyzed for total phosphorus, dissolved reactive phosphorus, fecal coliform, fecal streptococci, total suspended solids, and iron. In addition, sediment samples were collected and analyzed for total phosphorus, fecal coliform, and iron. TRC Omni also collected flow data and surveyed cross sections approximately every 500 feet along the mainstem of the stream.

To understand impacts of stormwater, TRC Omni developed hydrologic, hydraulic, and nonpoint source pollutant loading models of the watershed. Hydrologic modeling was performed in order to quantify the response of stream flows to precipitation. The Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS), and the Hydrologic Engineering Center's River Analysis System (HEC-RAS), both developed by the United States Army Corps of

Engineers, were used to simulate surface runoff originating in different areas of the Ramanessin Brook watershed and route the flow of the water through the stream network under various storm events. DAFLOW, developed by USGS, and WAMIT, developed by TRC Omni, were used to simulate velocities in the stream and to perform shear stress analyses to quantify erosion potential of the stream bed under various flow conditions. Finally, a pollutant loading model based on event mean concentrations (EMCs) was used to estimate expected nonpoint source pollutant loads for total suspended solids (TSS), total phosphorus (TP), and fecal coliform (FC) from surface runoff in the watershed.

Using these watershed modeling tools, several analyses were performed, including:

- Evaluating and mapping glauconitic soil erosion potential;
- Calculating peak flows and total stormwater volumes for individual subwatersheds using pre-developed, existing, and projected build-out land use conditions;
- Calculating shear stress in the stream to understand erosion of sediment under various flow conditions;
- Evaluating pollutant loading for total suspended solids, total phosphorus; and fecal coliform in individual subwatersheds, and
- Assessing water quality for the entire watershed using all available data.

These analyses provided insight into characteristics of the watershed that impact the Ramanessin Brook. The peak flow and total stormwater volume calculations demonstrate that any changes in watershed land uses that affect runoff have a more significant impact during storms of lower intensities than during storms of higher intensities. The simulations indicate that stormwater and watershed management implemented at a sub-watershed level can significantly impact peak flow rates and volumes during the smaller, more frequent storms that contribute the majority of the rainfall in the State of New Jersey over a given year.

In addition, these analyses demonstrate that land use changes that have already occurred have produced a much larger impact on storm runoff than any changes that might result from future development. Since the analyses performed do not account for BMPs, including those required for new development, they tend to overestimate the impact of new development. Despite this, the analyses show that existing development has had a more profound impact on stormwater characteristics than new development could. As a result, retrofits of existing infrastructure might be more beneficial than additional requirements on new development.

The shear stress analysis demonstrates that the shear stress at all the sampling stations in the Ramanessin Brook is considerably higher than the shear stress that would cause erosion during nearly all the rainfall events. From this, we can conclude that the stream bed of Ramanessin Brook is eroding during most rainfall events. Our analyses show that stormwater reduction BMPs would do little to prevent the stream bed from eroding.

The pollutant loading analyses for phosphorus clearly illustrates the importance of erosion of glauconitic soils, both from the watershed and in the stream itself, as a major source of phosphorus in the Ramanessin Brook. Phosphorus is highly correlated with TSS, iron, and turbidity. These correlations get stronger at downstream locations. Furthermore, the ratio of observed instream loads to estimated runoff loads increases dramatically at downstream locations. In other words, the observed levels of phosphorus at downstream locations cannot be fully explained by runoff loads. All of these observations show the importance of instream sediment erosion as a major source of phosphorus.

Total suspended solids (TSS) is also highly correlated with flow. In fact, during high flows, TSS exceeds the FW2-TM criterion in downstream areas. Furthermore, the ratio of observed instream loads to estimated runoff loads increases dramatically in downstream locations. In other words, the observed levels of TSS at downstream locations cannot be fully explained by runoff loads. Based on all these observations, instream erosion also represents a major source of TSS.

Fecal coliform analyses illustrate that samples taken during the summer have much higher fecal coliform concentrations than those taken during the winter. In fact, the 30-day geometric mean criterion appears to be exceeded at all sites, including the reference station, during the summer. However, the fecal coliform concentrations at the stream locations are much higher than at the reference location. High levels of bacterial contamination are observed at both low and high flows. During low flows, fecal coliform concentration increases as flow decreases.

This indicates a constant load that gets diluted by baseflow, such as failing septic discharges or perhaps direct deposition by resident waterfowl or other wildlife. During high flows, fecal coliform concentration also increases as flow increases. This clearly indicates high runoff loads being delivered to the stream. Fecal coliform appears to be correlated with TSS during high flows when TSS is high.

While only two sediment samples were analyzed for fecal coliform, no bacteria was observed in one sample, and in the second, bacteria was only observed at the minimum detection limit of 10 colonies/gram. Furthermore, the ratio of observed instream loads to estimated runoff loads does not increase substantially at downstream locations, and is generally less than one. In other words, the observed fecal coliform levels may be explained based on runoff and baseflow loads. This study did not find any evidence for the proposition that fecal contamination is caused by erosion of bacteria-rich sediments.

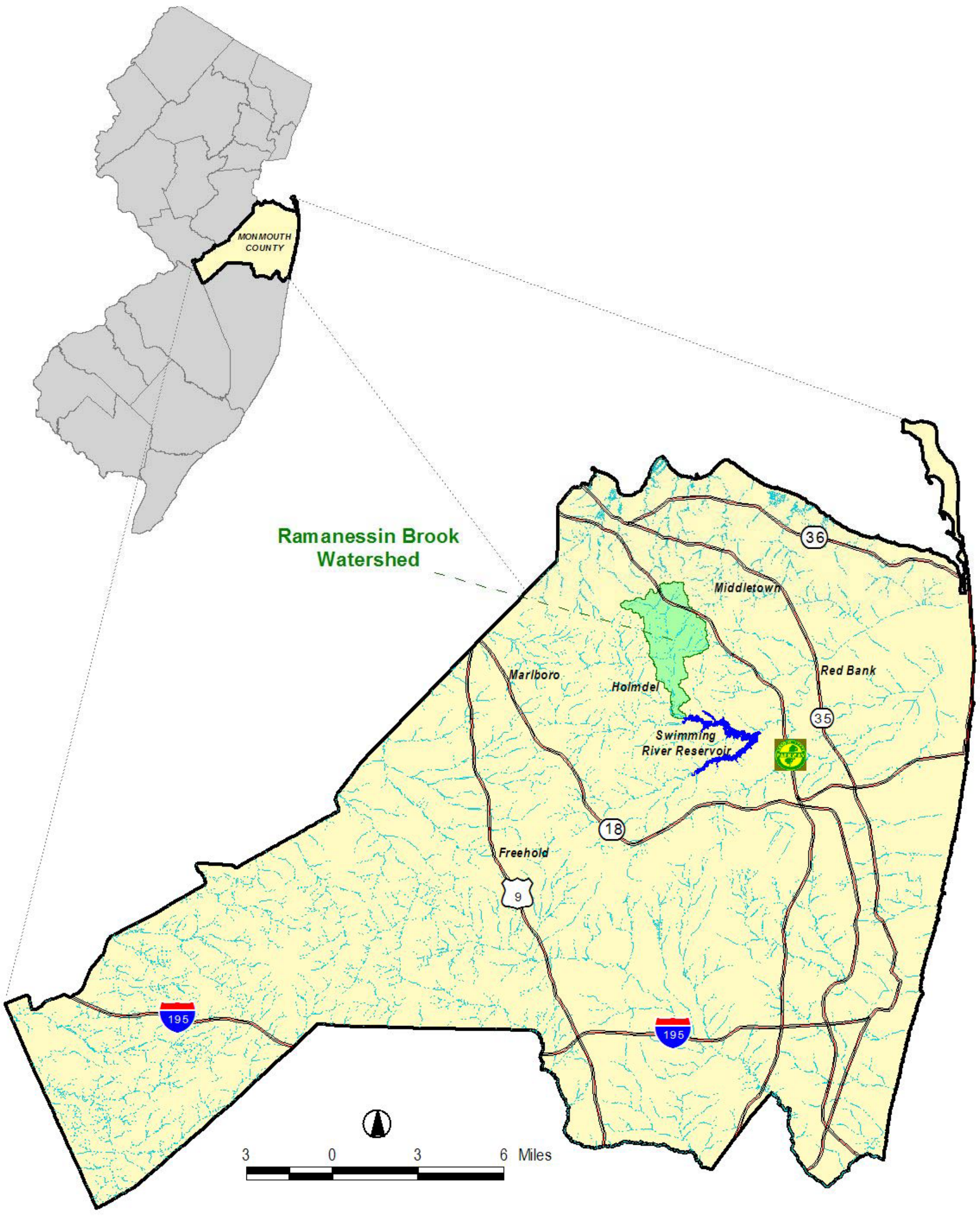
Based on these findings several recommendations are set forth for further analysis and mitigation of nonpoint source pollutants in the Ramanessin Brook watershed (See Chapter VI).

I. Introduction

The Ramanessin Brook NPS Pollution Source Assessment and Stormwater Impact Study, funded through a NJDEP 319h grant to the Monmouth County Planning Board, was completed to evaluate the sources of fecal coliform and phosphorus in the Ramanessin Brook in Holmdel Township, New Jersey (Figure 1). In support of this effort, TRC Omni developed a watershed pollutant-loading model, hydrologic model, and hydraulic model to assess water quality impacts due to nonpoint source pollutants, in particular erosion and stormwater runoff. NJDEP designated the Ramanessin Brook as impaired by fecal coliform and total phosphorus in its Integrated List of Waterbodies (NJDEP, 2004). Building on important research conducted by the Monmouth County Health Department, this project serves to evaluate the link between glauconitic soils and fecal coliform and total phosphorus. This project is a critical first step in addressing stormwater management in impaired watersheds throughout Monmouth County and WMA 12. In addition to the pollutant source evaluation, this study serves as the starting point for the development of a Regional Stormwater Management Plan for communities in the Ramanessin Brook and greater Navesink-Swimming River watershed.

This project provides communities within the Ramanessin Brook watershed with an important tool they will need to improve water quality and prepare a comprehensive Regional Stormwater Management Plan. As these issues are a concern in many impaired waterways of WMA 12, the work completed under this project also provides necessary information to other communities in the region as they plan for stormwater management.

Figure 1. Geographic Location of Ramanessin Brook Watershed



II. Watershed Characterization

Existing conditions were characterized in terms of surface hydrology, land use, soils, floodplains and wetlands, groundwater recharge, and riparian corridor and stream bank conditions. These characteristics are illustrated in the characterization maps in Appendix A. In addition, water quality impairments were summarized from the New Jersey Department of Environmental Protection (NJDEP) 2004 Integrated List of Waterbodies.

A. Surface Hydrology

Headwaters of the Ramanessin Brook originate at the PNC Bank Arts Center and Phillips Park. From this point, the stream meanders south for approximately 5 miles through public, private, agricultural, residential, and forested lands until it reaches the Swimming River Reservoir (Appendix A - Map 1). Development in the Ramanessin watershed is creating more impervious surface, which contributes to the flashy nature of the Brook and its tributaries. Impervious surfaces reduce groundwater recharge and stream baseflow, and increase stream velocities, flows, and, potentially, nonpoint source pollutants discharged to the waterway and reservoir. The watershed falls nearly 300 feet from its upper reaches to the mouth of Ramanessin Brook at the Swimming River Reservoir (Appendix A - Map 2).

B. Land Use

Land use maps and GIS coverages were obtained from the 1995/97 Land Use/Land Cover datasets available from NJDEP. A generalized land use characterization map for the Ramanessin Brook watershed is provided in Appendix A (Map 3).

For the analysis conducted in the GIS-based pollutant loading model/water quality model described later, the land uses were lumped into six major land use types: Urban Commercial, Urban Residential, Forest, Agricultural, Wetlands, and Barren Land. Table 1 provides the acreage and percentage of the study area for each of these land use types.

Table 1. General Land Use Types in the Ramanessin Brook

LAND USE	AREA (Acres)	% AREA
RESIDENTIAL	1137.6	28.1
AGRICULTURE	738.0	18.3
FOREST	729.7	18.1
COMMERCIAL	681.3	16.9
WETLANDS	678.4	16.8
BARREN LAND	47.4	1.2
WATER	29.6	0.7

C. Soils

Soils in this region of Monmouth County are dominated by the Freehold – Urban land – Collington complex described in the general soils map of Monmouth County. These soils are characterized as deep, well-drained, loamy soils. This soil group accounts for 50 percent of the area in the drainage basin. Soils that make up the stream bottoms in this area are classified as Humaquepts, Frequently flooded – Manahawkin. These soils are nearly level, deep, somewhat poorly drained, sandy soil located in floodplains and lowland areas. These account for 26 percent of the area in the drainage basin. Additional soils in the drainage basin include the Colts Neck, Holmdel, Phalanx and Shrewsbury. Map 4 illustrates how these soils are distributed throughout the watershed.

The soils of the drainage basin are relatively high in glauconite, a mineral deposit of marine origin, present in soil formations throughout Monmouth and Burlington counties (Tedrow, 2002). Glauconite consists of sand-sized pellets of clay mica. It is rich in iron and generally observed as a greenish aggregate (also called greensand). Because glauconitic soils contain unconsolidated sand-sized pellets, they are highly erodable. Being rich in iron and composed of clay, glauconitic soils have a high cation exchange capacity. The glauconite content of the soils in the Ramanessin Brook basin can range from 0 percent to as high as 40 percent. An area-weighted average glauconite content for soil in the drainage basin is about 7 percent. Further discussion of consequences of this unique soil characteristic is included in subsequent portions of this report.

D. Floodplains and Wetlands

Extensive wetland areas exist along the mainstem of the Ramanessin Brook and its tributaries. In total, over 1,200 acres of wetlands exist, nearly 80 percent of which are characterized as deciduous wooded wetlands. Characteristic of this steep gradient watershed, a narrow floodplain area exists along the mainstem of the Ramanessin but is not delineated along any of the tributaries. The floodplain lies within the wooded wetland corridor that remains along nearly the entire 5 miles of the Brook. Extensive downcutting of the stream bed has occurred, resulting in steep banks throughout much of the stream reaches. The delineated floodplain is generally not over 250 feet in width except near the mouth of the Brook near the Swimming River Reservoir, where the floodplain expands to nearly 500 feet in width. Floodplain and wetland areas are illustrated in Appendix A - Map 5.

E. Groundwater Recharge

Generally, groundwater recharge rates in the basin are above average with an area-weighted average recharge of 10.4 inches per year. The basin contains urban areas that have no infiltration and areas of upland that infiltrate between 11 and 15 inches per year (Appendix A - Map 6). Lowlands near the streams act as discharge areas and do not receive a net recharge over the course of a year.

F. Riparian Corridor and Stream Bank Conditions

The riparian corridor along the Ramanessin Brook is dominated by wooded wetland areas and steep slopes. Significant areas of continuous undisturbed woodlands remain along the mainstem of the Ramanessin and on portions of its tributaries. Encroachment in the riparian corridors of the tributaries has occurred in many areas and many of these corridors are now characterized as agricultural wetlands or have been converted to turf areas within suburban developments. The stream banks are generally very steep, and the channel of the stream has down cut through soils, leaving exposed soils on the banks that in some cases are 6 to 8 feet in height.

G. Water Quality Impairments

According to the 2004 Integrated List of Waterbodies (NJDEP, 2004), almost every assessed waterway leading to the Swimming River Reservoir is faced with the same impairments as are found in the Ramanessin Brook: aquatic life, fecal coliform, and phosphorus. These impairments have been identified as major priorities for the region and the State of New Jersey by the project partners. On the Ramanessin Brook (listed as "Hop Brook"), two AMNET locations identify the stream as severely to moderately impaired, respectively, north to south (ANO465 & ANO466) based on macroinvertebrate sampling. Furthermore, NJDEP has identified water quality impairments for fecal coliform (FC) and total phosphorus (TP) in the Ramanessin Brook based on data from the Ramanessin Brook at Willow Brook Road (Station No. 53); these data were collected by the Monmouth County Health Department under a NJDEP-approved QA/QC program. The impaired stream segments and the sampling locations used to assess Ramanessin Brook are shown on Map 7 in Appendix A.

III. Watershed Sampling

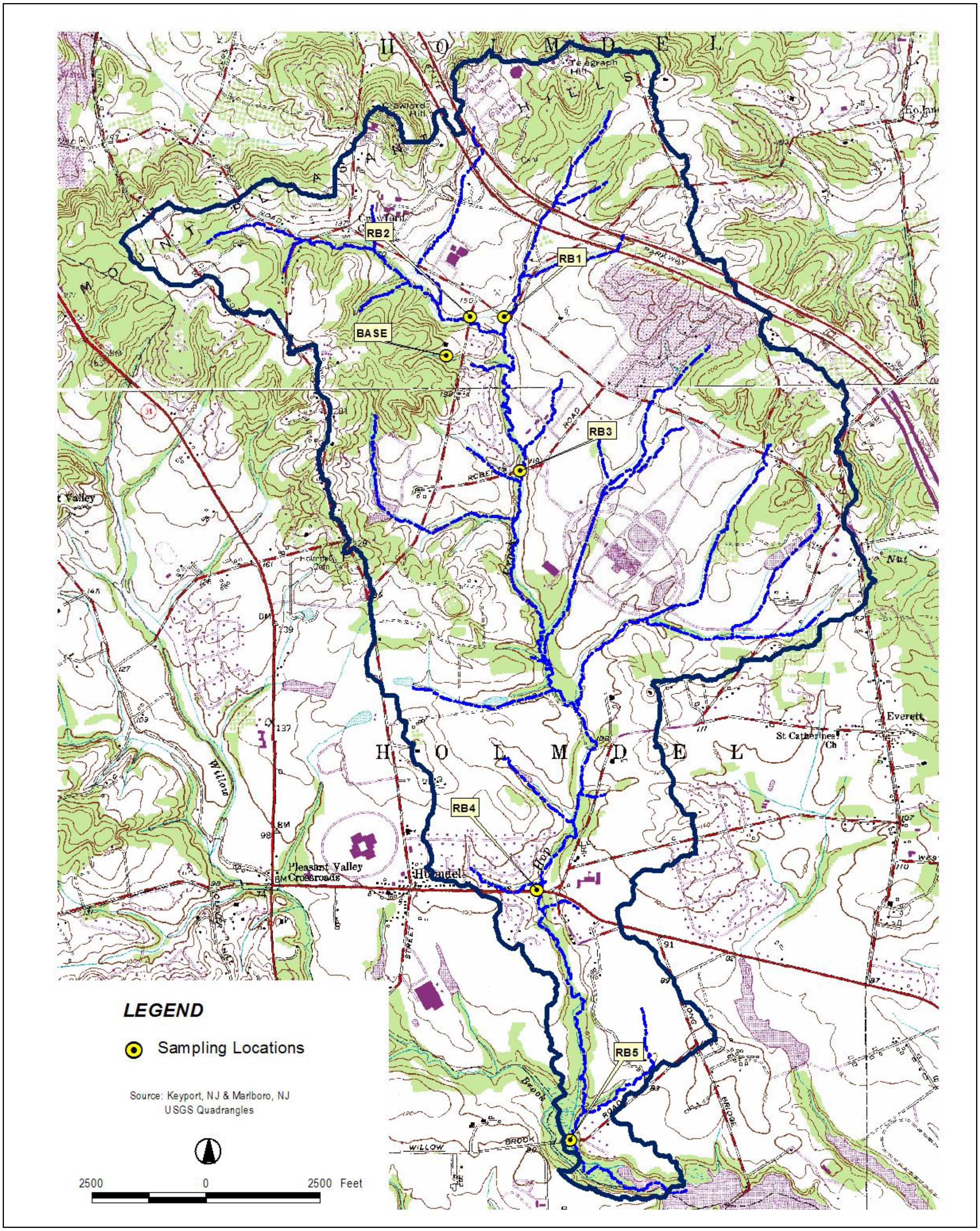
A Quality Assurance Sampling Plan (QASP) for the Ramanessin Brook Nonpoint Source Assessment and Stormwater Impact Study (April 13, 2004) was prepared by TRC Omni for the Monmouth County Planning Board. The purpose of this project was to provide data to develop a watershed pollutant loading and hydrologic model to better understand the relationship between hydraulic conditions and the targeted pollutants. The sampling for this project was performed to obtain data necessary to evaluate phosphorus and fecal coliform concentrations with respect to flow conditions, seasonal variations, and pertinent weather conditions for a study period of one year. This sampling plan was designed to assess water quality impairment due to nonpoint source impacts including erosion and stormwater runoff. In addition, the information provided by this study was expected to aid in developing a Regional Stormwater Management Plan, because almost every other waterway that supplies water to the Swimming River Reservoir has similar impairments to those found in the Ramanessin Brook.

In order to develop the hydraulic model, a survey of stream bathymetric data, including stream cross-sections and channel conditions, was completed from the headwaters of the Ramanessin Brook, at the bridge serving the northbound lanes of the Garden State Parkway to just upstream of the Swimming River Reservoir at the Willow Brook Bridge. TRC Site measured 55 detailed cross-sections and were accompanied by a TRC Omni field technician who photographed and documented site conditions as well as took GPS readings at each cross-section. The cross-section survey data are contained in the digital files within Appendix G.

A. Water Quality Sampling

Sampling and analyses were performed in accordance with the QASP for the Ramanessin Brook. A total of five stream sampling station locations were sampled bi-weekly from July 2004 to June 2005 and one background station was sampled six times from July 2004 to October 2004. A USGS topographic map of monitoring station locations is shown in Figure 2.

Figure 2. USGS Topography and Sampling Stations



Site RB1 is located on the North Branch of the Ramanessin Brook, just upstream of the confluence with Hop Brook (also known as West Branch Ramanessin Brook), at the upper end of the spatial extent. Site RB2 is located on West Branch Ramanessin Brook upstream from the confluence of the North and West Branches of Ramanessin Brook. Site RB3 is located downstream of the confluence of the North and West Branches of Ramanessin Brook and was chosen to characterize the segment of the Ramanessin Brook immediately upstream of the Lucent Corporate Center. RB4 is located just downstream of the unnamed tributary to Ramanessin Brook at the lower end of the spatial extent influenced by recent residential development within the Borough of Holmdel. Site RB5, located at Willow Brook Road, characterizes the Ramanessin Brook at the lower end of the spatial extent of this study. The background (BASE) location is located on an unnamed tributary to Ramanessin Brook and was chosen to characterize the naturally occurring sources of iron and phosphorus leached into the water column from glauconitic bedrock formations in the area, and to characterize other baseline (background reference) conditions. Sampling at each station was performed as detailed below:

Chemical and Biological Analysis Stations:

- RB1, RB2, RB3, RB4, RB5 and BASE

Flow Monitoring Stations:

- RB1, RB2, RB3, RB4 and RB5

Chemical Soil Analysis Stations:

- RB1, RB2, RB3, RB4 and RB5

Particle Size Soil Analysis Stations:

- RB3 and RB5

Sampling at the Ramanessin Brook chemical and biological analysis stations occurred approximately once every two weeks for one year beginning July 2004 and ending June 2005. Sampling occurred independent of weather conditions, and within the study period, a total of 24 sample collection events were conducted during a range of flow conditions: five high-flow events, 13 ambient events, and six low-flow events. RB5, the most downstream location, was used as the event type indicator. An event was considered high flow if the flow at RB5 was 15 cubic feet per second (cfs) or above, ambient flow if the flow was between 5 cfs and 15 cfs, and low flow if the flow was below 5 cfs. Sampling at the BASE location occurred during seven events: one high-flow event, three ambient events, and three low-flow events.

Parameters for which the water quality samples were analyzed were selected specifically to gain insight into the phosphorus and fecal coliform impairments in the stream. Total phosphorus and fecal coliform were measured because these are the constituents for which the stream is listed as impaired. Dissolved reactive phosphorus was measured because this is the form of phosphorus that is available for uptake by plants and algae. While phosphorus is an essential nutrient for plants and algae, it is considered a pollutant because it can stimulate excessive plant and algal growth. In addition to fecal coliform, fecal streptococcus was measured in many of the water samples, because the ratio between fecal coliform and fecal streptococcus may provide insight into whether the source of the bacteria is human or wildlife. Total suspended solids (TSS) and turbidity were analyzed in order to better understand the relationships among phosphorus, fecal coliform, and sediment particles in the water column. Iron was analyzed because it is an important chemical component of glauconite and binds phosphorus in the presence of oxygen. Finally, flow was measured in order to quantify loads and gain insight into the flow conditions under which exceedances of water quality criteria are observed. Results of all water quality monitoring, flow monitoring, and sediment sampling are provided in Appendices B, C, and D, respectively.

B. Stream Flow Monitoring and Precipitation

During each sample event in Ramanessin Brook, flow was determined by measuring velocity and depth across established transects following the sample collection at each flow monitoring station. Appendix C contains figures showing each flow monitoring location's flow by date as measured in cubic feet per second. Additionally, pressure transducers with data loggers were installed at RB1, RB2, RB3, RB4, and RB5 to monitor depth continuously from August 2004 to January 2005. A detailed analysis of these continuous data is presented in the HEC-HMS flow calibration and validation sections of this report. In addition, at each flow monitoring station, velocity profiles were taken during an ambient event at three locations across the stream, one at the right bank, one at the left bank and one at center stream. In addition, during an ambient event, detailed cross-sections were taken of each flow monitoring station.

Hourly precipitation data were obtained for two locations in the study area, Holmdel and Fort Monmouth, both of which are weather stations maintained by the South Jersey Resource Conservation and Development Council. The station at Holmdel was installed by Monmouth County specifically for this study, and was used as the primary source of precipitation data, with data from Fort Monmouth being used to supplement periods where no Holmdel data were available. There were many periods where the rain gages and/or data loggers were malfunctioning. As a result, no data were available for the following time periods: 8/23/04 to 8/28/04, 10/8/04 to 11/2/04, 12/17/04 to 12/22/04, 2/8/05 to 2/12/05, 3/27/05 to 4/28/05, 5/5/05 to 5/15/05, 5/19/05 to 5/29/05, 6/12/05 to 6/13/05, and 6/18/05 to 6/27/05. In total, for nine of the 24 TRC Omni sample events, no precipitation data was available for hydrograph analysis. These sample event dates were 10/15/04, 10/19/04, 12/22/04, 2/8/05, 3/30/05, 4/6/05, 4/13/05, 5/20/05, and 6/2/05. Two of these events, 10/19/04 and 5/20/05, were high flow events.

C. Sediment Sampling

Stream bank and sediment material was collected with a soil auger at each of the designated sampling locations. The soil from depths of 3 inches to 6 inches was composited and analyzed as a single sample for each of the sample stations. All soil and sediment were analyzed for total solids, fecal coliform, and total phosphorus.

Samples were collected from RB1, RB2, RB3, RB4, and RB5 during one event. Soil from the bank of sample station RB3 and the sediment of sample station RB5 were taken during an ambient event and analyzed for particle size. The chemical results and particle size results of the bank and sediment analysis are presented in Appendix D. Bank and bed results were nearly identical, and results between sites were similar as well.

IV. Watershed Modeling

Watershed modeling efforts were undertaken with a number of objectives:

- to better understand the response of stream flows to precipitation;
- to provide a basis for evaluating flooding potential;
- to better understand stream erosion potential under various flows;
- to better understand potential sources of pollutants in the stream; and
- to evaluate the impact of land use changes on all of the above.

A. Hydrologic Model

Hydrologic modeling was performed in order to quantify the response of stream flows to precipitation. The Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS), and the Hydrologic Engineering Center's River Analysis System (HEC-RAS), both developed by the United States Army Corps of Engineers, were used to simulate surface runoff originating in different areas of the Ramanessin Brook watershed and route the flow of the water through the stream network under various storm events.

HEC-HMS is designed to simulate the precipitation-runoff processes of dendritic watershed systems such as Ramanessin Brook. HEC-HMS has algorithms to simulate infiltration losses, surface runoff, and open channel routing, and allows different methods to be used to simulate these processes (U.S. Army Corps of Engineers, 2001). HEC-HMS has two main model components: a basin model and a meteorological model. The basin model component contains watershed elements, such as sub-basins, junctions and reaches, their properties, and connectivity. The meteorological model component contains precipitation types and intensity. HEC-HMS provides as a final result the hydrograph (flow vs. time plot) and peak flow for model elements such as sub-basins, junctions, and reaches.

Due to the availability of extensive GIS data coverages for the watershed, including soils, land use, and topography datasets, modeling set up and post processing was completed using an ArcView GIS Interface. A GIS interface using ESRI's ArcView software is available for HEC-HMS. The GIS interface for these models allows input files and parameters to be derived from spatial databases, such as digital elevation models

(DEMs) and land use/land cover layers. HEC-GeoHMS ArcView interface software was used to derive the input data for the hydraulic model.

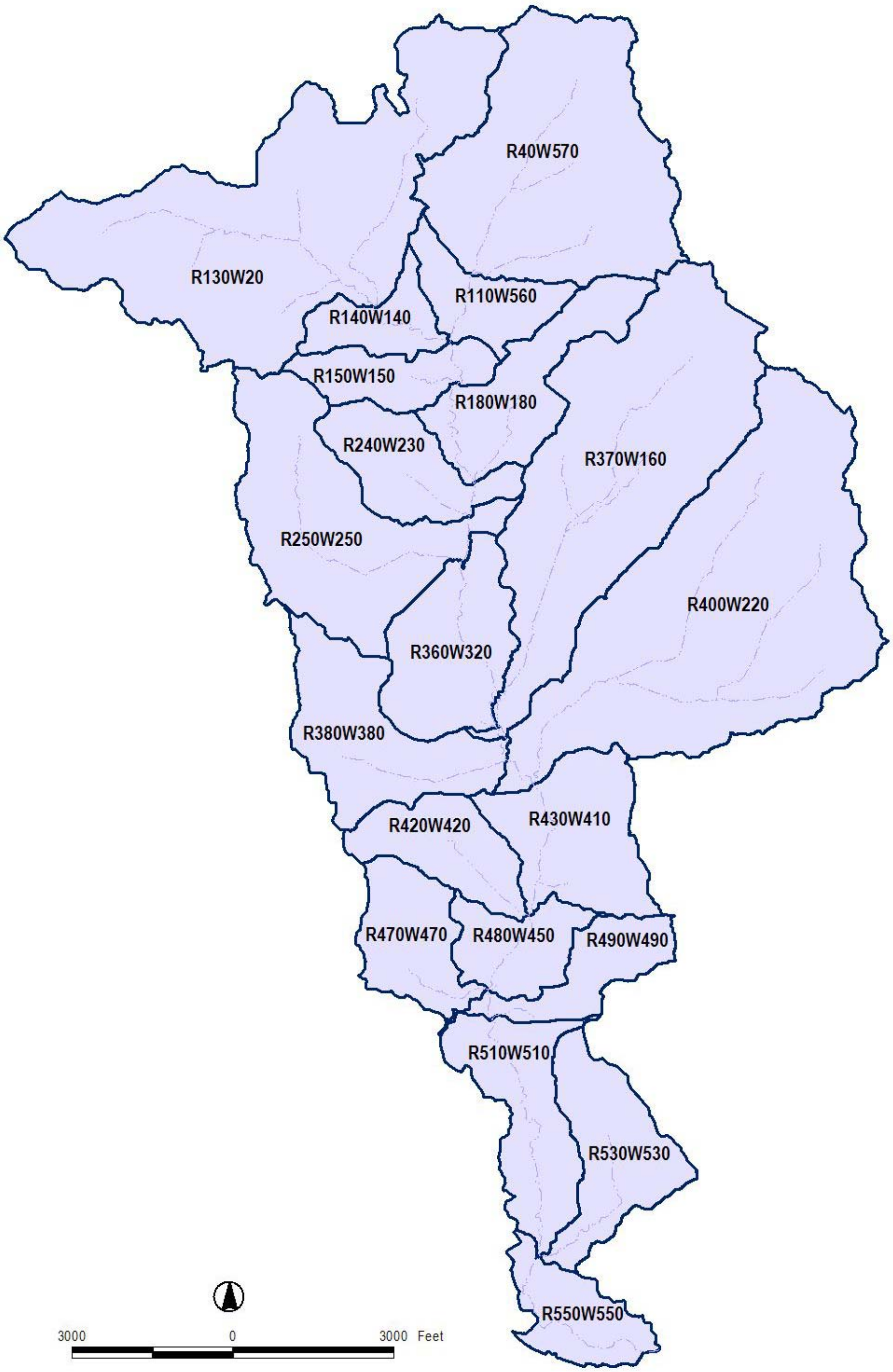
1. HEC-HMS Basin Model Setup

The basin model contains the system's elements, their relationships, and parameters. The definition of the system's elements starts with the delineation of sub-basins. The delineation captures drainage areas of the major tributaries and reservoirs within the system. These drainage areas represent sources of incremental and boundary flows to the system. Each sub-basin has individual characteristics that influence precipitation-runoff processes.

The HEC-GeoHMS extension was used to subdivide the Ramanessin Brook watershed into 20 sub-basins. To delineate sub-basins for the Ramanessin Brook watershed, a digital elevation model (DEM) derived from two-foot contour data provided by Monmouth County was used.

The sub-basins are the basic elements of the system, where surface runoff and base flow are generated. After the sub-basins were defined, they were connected through a network of channels. The HEC-GeoHMS extension creates a stream network connecting the sub-basins. Sub-basins as well as junctions, reaches and their connectivity are key elements necessary for the basin HEC-HMS model. The HEC-GeoHMS extension creates all these elements automatically based on digital datasets. Figure 3 identifies each of the individual HEC-HMS sub-basins delineated for the hydrologic model of the Ramanessin Brook watershed.

Figure 3. HEC-HMS Sub-Basins



a. HEC-HMS Basin Model Methods

For the Ramanessin Brook watershed modeling, the Soil Conservation Service (SCS) curve number method was used to determine runoff from each sub-basin. The SCS curve number method requires an estimation of a composite curve number. For each individual sub-basin in the Ramanessin Brook watershed, a composite curve number was estimated using the SCS curve number method.

The curve number is a function of land use, hydrologic soil group, and available soil moisture. The 1995 land use/land cover data coverage available from the NJDEP GIS database and the Natural Resources Conservation Service (NRCS) SSURGO soils were used to determine average soil moisture condition curve numbers for each land use and soil combination in the Ramanessin Brook watershed. The composite (area-weighted average) curve numbers were obtained using spatial analysis techniques and spatial databases within the GIS.

Areas with unique combinations of land use and soil type, and consequently hydrologic soil groups, were obtained by overlaying land use and soil datasets. These overlay processes created several polygons representing distinct combinations of these characteristics. Each of these polygons was assigned a curve number (CN) using tables published by the SCS in Technical Report 55 (SCS, 1986). Table 2 presents CN values for land uses present in the Ramanessin Brook watershed as depicted in TR55 tables. Table 3 presents a summary of each sub-basin's area and composite curve number.

Table 2. Average Moisture Condition Curve Numbers for Ramanessin Brook Watershed

LAND USE	HYDROLOGIC SOIL GROUP			
	A	B	C	D
AGRICULTURAL WETLANDS (MODIFIED)	98	98	98	98
ALTERED LANDS	NA	94	94	NA
ARTIFICIAL LAKES	94	94	NA	94
ATHLETIC FIELDS (SCHOOLS)	49	69	79	84
COMMERCIAL/SERVICES	89	92	94	95
CONIFEROUS BRUSH/SHRUBLAND	NA	NA	70	NA
CONIFEROUS FOREST (>50% CROWN CLOSURE)	36	60	NA	NA
CONIFEROUS FOREST (10-50% CROWN CLOSURE)	NA	60	NA	NA
CROPLAND AND PASTURELAND	67	77	83	87
DECIDUOUS BRUSH/SHRUBLAND	35	56	70	77
DECIDUOUS FOREST (>50% CROWN CLOSURE)	36	60	73	83
DECIDUOUS FOREST (10-50% CROWN CLOSURE)	NA	60	73	79
DECIDUOUS SCRUB/SHRUB WETLANDS	NA	98	98	98
DECIDUOUS WOODED WETLANDS	98	98	98	98
DISTURBED WETLANDS (MODIFIED)	NA	98	NA	98
FORMER AGRICULTURAL WETLAND (BECOMING SHRUBBY, NOT BUILT-UP)	NA	98	NA	NA
HERBACEOUS WETLANDS	98	98	98	98
INDUSTRIAL	NA	88	NA	93
MANAGED WETLAND IN MAINTAINED LAWN GREENSPACE	NA	98	NA	98
MIXED DECIDUOUS/CONIFEROUS BRUSH/SHRUBLAND	NA	56	70	77
MIXED FOREST (>50% CONIFEROUS WITH >50% CROWN CLOSURE)	NA	60	73	NA
NATURAL LAKES	100	100	100	100
OLD FIELD (< 25% BRUSH COVERED)	30	58	71	NA
ORCHARDS/VINEYARDS/NURSERIES/HORTICULTURAL AREAS	NA	73	82	86
OTHER AGRICULTURE	NA	73	82	NA
OTHER URBAN OR BUILT-UP LAND	49	69	79	84
PLANTATION	NA	65	NA	NA
RECREATIONAL LAND	NA	69	79	84
RESIDENTIAL, RURAL, SINGLE UNIT	46	68	79	84
RESIDENTIAL, SINGLE UNIT, LOW DENSITY	48	66	79	83
RESIDENTIAL, SINGLE UNIT, MEDIUM DENSITY	NA	72	NA	86
TRANSITIONAL AREAS	NA	85	89	NA
TRANSPORTATION/COMMUNICATIONS/UTILITIES	89	92	NA	95

NA – Not Applicable
The curve numbers were obtained from SCS TR 55 (SCS, 1986).

Table 3. Ramanessin Brook Sub-Basin Composite Curve Numbers

Sub-Basin	Area (Acres)	CN Area Wt
R110W560	79.135	77
R130W20	584.168	72
R140W140	62.048	74
R150W150	76.699	70
R180W180	137.761	76
R240W230	108.032	74
R250W250	280.094	71
R360W320	153.916	83
R370W160	474.464	75
R380W380	174.073	83
R400W220	632.462	76
R40W570	404.970	69
R420W420	99.585	86
R430W410	154.503	80
R470W470	101.691	72
R480W450	80.691	79
R490W490	78.651	74
R510W510	141.138	83
R530W530	134.599	82
R550W550	83.200	84

2. HEC-HMS Meteorological Model Setup

The meteorological model setup consists of defining storm characteristics. The meteorological model contains a precipitation method and, optionally, an evapotranspiration method. The model can simulate precipitation according to different methods. Lumped methods such as the SCS hypothetical storm, user precipitation hydrograph, or grid precipitation methods are available, among others.

As detailed local rainfall data was available for the Ramanessin Brook watershed, the user precipitation hydrograph method was used to best simulate actual conditions in the watershed. Hourly precipitation data from Holmdel weather station, which is the available weather station within the Ramanessin Brook watershed, was input into the model.

In addition, the SCS hypothetical storm method was used to obtain peak flows from individual sub-basins for various 24-hour rainfall events. Hypothetical rainfall corresponding to the 1, 2, 10, and 100-year storms were entered as model parameters.

Table 4 summarizes 24-hour rainfall depths for Monmouth County for different design storms. Complete tables containing data for New Jersey rainfall events are included in Appendix E.

Table 4. Monmouth County Rainfall Totals for Standard Design Storms

TYPE III STORM	24-HR RAINFALL (INCHES)
1-Year Storm	2.9
2-Year Storm	3.4
10-Year Storm	5.2
100-Year Storm	8.9

3. HEC-HMS Simulation and Output

After the basin model and meteorological model were set up, the model controls, such as period of simulation and time step, were defined in order to proceed with the simulation. For the Ramanessin Brook watershed model, a six-month simulation starting from November 3, 2004 and ending May 4, 2005 was performed with 10-minute time steps and 24-hour simulations were performed for all the hypothetical storm events with 5-minute time steps.

Model results can be seen in a graphical or table format for all junctions, reaches, sub-basins, and impoundments. The hydrographs for all the sub-basins were exported to the Watershed Model Integration Tool (WAMIT, see section B.2. below) in order to generate velocities at various locations in the river. The peak flows at the junctions were entered into HEC-RAS and can be used to determine flooding and water surface elevation profiles.

B. Hydraulic Model

Two hydraulic modeling analyses were conducted to calculate velocities at various locations in the Ramanessin Brook. HEC-RAS, a one-dimensional hydraulic model, was used in steady state to route the stream flow and can be used to produce water surface elevation profiles from the flows generated by HEC-HMS under various hypothetical storm events. DAFLOW, as discussed previously, was used along with WAMIT (see description below) to route unsteady flows generated by HEC-HMS for various sub-watersheds and to calculate depths, velocities, and shear stress at various locations in the stream.

1. Modeling with HEC-RAS

The steady state flow – water surface profile component of HEC-RAS was used to develop a hydraulic analysis of the Ramanessin Brook watershed. HEC-RAS can be used to produce water surface elevation profiles from the flows generated by HEC-HMS under various hypothetical storm events. Water surface elevation profiles are used to evaluate the extent of flooding potential in a watershed, and are expected to be developed in the future by Monmouth County as part of a regional stormwater planning project.

The HEC-RAS water surface elevation component bases its simulations on cross-sectional geometry and pre-defined steady flows. The effects of obstructions such as bridges, culverts and weirs are considered in the computations. In order to perform water surface profile calculations in HEC-RAS, cross-sectional geometry, channel obstructions and steady flows at various locations within the system network need to be identified. Inputs for HEC-RAS are entered in two distinct modules: geometry data and steady flow data. The geometry data module contains the river system network, cross-section information and channel obstructions. The steady flow model contains flow boundary conditions and flow data.

a. Geometry Data for HEC-RAS

Geometry data consist of stream network connectivity, cross-section data, and hydraulic structure data. In the case of the Ramanessin Brook watershed model, stream network connectivity and cross-section data were entered using the HEC-GeoRAS interface. HEC-GeoRAS is an ArcView GIS interface that automatically creates stream network connectivity and cross-section inputs for HEC-RAS based on spatial datasets. Although the HEC-GeoRAS interface has the potential to speed up the data entry process in HEC-RAS, the quality of the inputs, and consequently model accuracy, are a function of the quality of the spatial datasets.

For the Ramanessin Brook study, geometry was derived based on existing spatial databases provided by Monmouth County and NJDEP. A digital terrain model (DTM) was derived based on a two-foot contour digital data set provided by Monmouth County. The original two-foot contour data was processed using the ArcView 3D analyst extension to create the DTM in an Arcinfo TIN format. Map 2 illustrates the Ramanessin Brook watershed DTM.

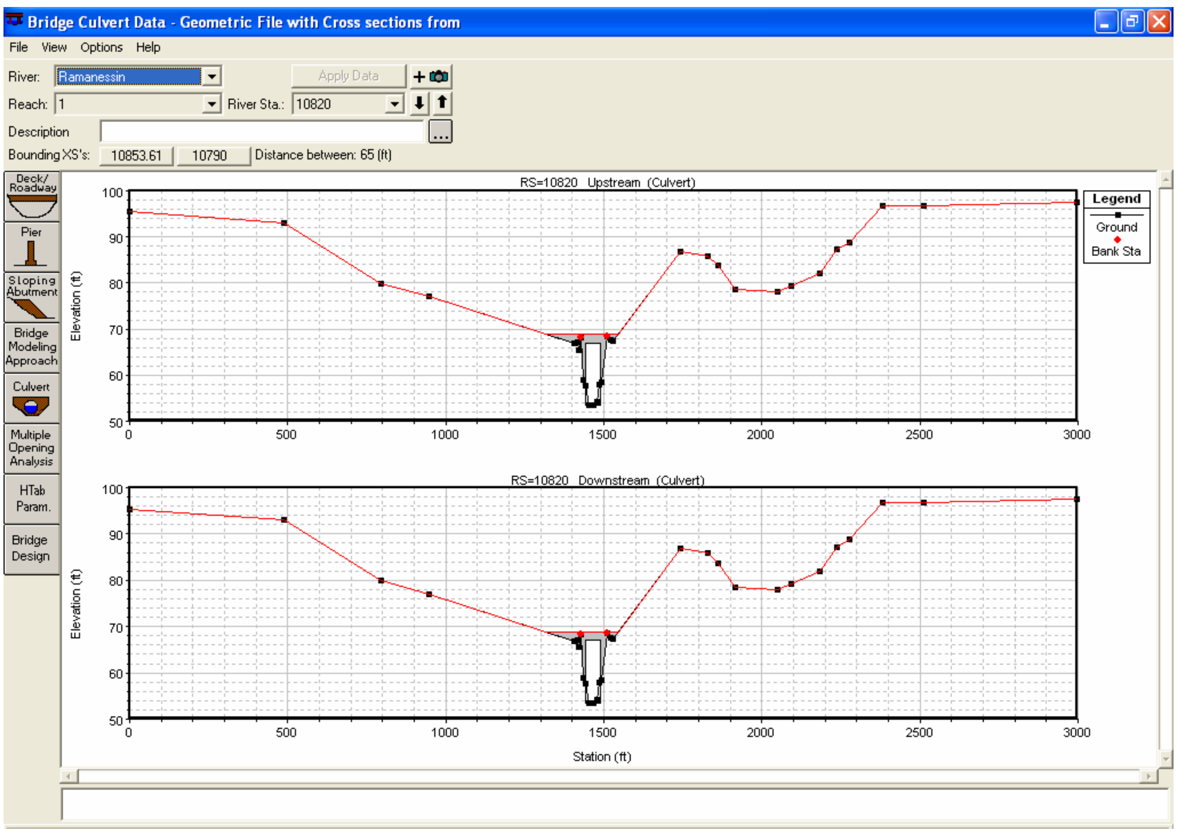
A two-foot contour provides enough resolution for depicting the shape of the floodplain. However, it provides a rather coarse representation of the stream banks and channel. An adequate representation of bank elevations and the stream bed is essential for HEC-RAS simulations. In order to overcome the poor representation of elevations by the DTM, within the vicinity of the stream bed and banks, field survey data provided by TRC Site at approximately every 500 feet was incorporated into the model. Appendix H contains the supplementary field survey data used to refine the HEC-RAS geometry.

A stream centerline is used by HEC-GeoRAS to establish the river reach network. The Ramanessin Brook stream centerline was digitized based on the 2002 MrSID digital imagery available for Monmouth County.

As was mentioned previously, the two-foot resolution DTM elevation data provides a poor representation of the stream bed and banks. Therefore, station elevations on the stream bed and near the banks were adjusted at a total of 54 cross-sections along the river reach network based on the field survey data collected by TRC Site, using the HEC-RAS graphical interface.

In addition to RAS floodplain elevations and stream geometry, channel obstructions are also part of the geometry data set for HEC-RAS. Obstructions can significantly influence water surface elevation profiles; therefore, it is crucial to have an adequate representation of such structures. Typical obstructions include bridges, culverts, and weirs. Structures that impact the flow in Ramanessin Brook and its tributaries had to be identified. Field surveys were conducted to locate bridges and culverts; spatial datasets were also used to identify the existence and locations of such structures. The data needed to enter obstruction information in the model was obtained from field surveys conducted by TRC Omni. A total of four bridges/culverts were identified and included in the HEC-RAS model for the Ramanessin Brook study (e.g. Figure 4).

Figure 4. Upstream and Downstream Cross-Sections for the Bridge at RB4 over Ramanessin Brook



b. Steady Flow Data for HEC-RAS

In order to simulate water surface elevation profiles for Ramanessin Brook, steady flow data have to be entered in HEC-RAS. Flow entries for HEC-RAS are obtained from HEC-HMS. A description of the methods to obtain the steady flows at desired locations is discussed in the hydrologic modeling section of this report. For the Ramanessin Brook watershed water surface elevation calculations, flow entry locations in HEC-RAS were assumed as being the most upstream cross-section of each reach. The output of interest from HEC-HMS is the peak flow at junctions located at upstream boundaries and reach intersections.

The shape of the river network for Ramanessin Brook is the same for HEC-RAS and HEC-HMS models. However, the identification of its elements, such as junctions and reaches, is different because of model characteristics. Therefore, junctions in HEC-HMS were overlaid with HEC-RAS cross-sections to identify flow entry locations in HEC-RAS. After the junctions of HEC-HMS were assigned to respective cross-sections in HEC-RAS, the peak flows for the selected junctions were input into HEC-RAS for the various design storms.

HEC-RAS can simulate water profiles according to different scenarios of flows, which allow, for example, the establishing of the 1, 2, 10, and 100-year flood perimeter, which is a function of the peak flows for different design storms, calculated using HEC-HMS. Again, the HEC-RAS model developed for the Ramanessin Brook Watershed was used to simulate steady-state flows during hypothetical storms.

2. Modeling with DAFLOW and WAMIT

a. DAFLOW

DAFLOW is a one-dimensional model used to calculate stream flows at individual time steps and locations using sub-basin incremental flows generated by HEC-HS. Typical model inputs include stream network elements, geometric characteristics, the time series of flow for upstream boundaries, and incremental flows from tributaries or sub-basins along the streams. Data are assigned to individual nodes defined in the stream network and. DAFLOW provides as output the discharge at each node, calculated cross-sectional area, calculated top width, and the input tributary inflow.

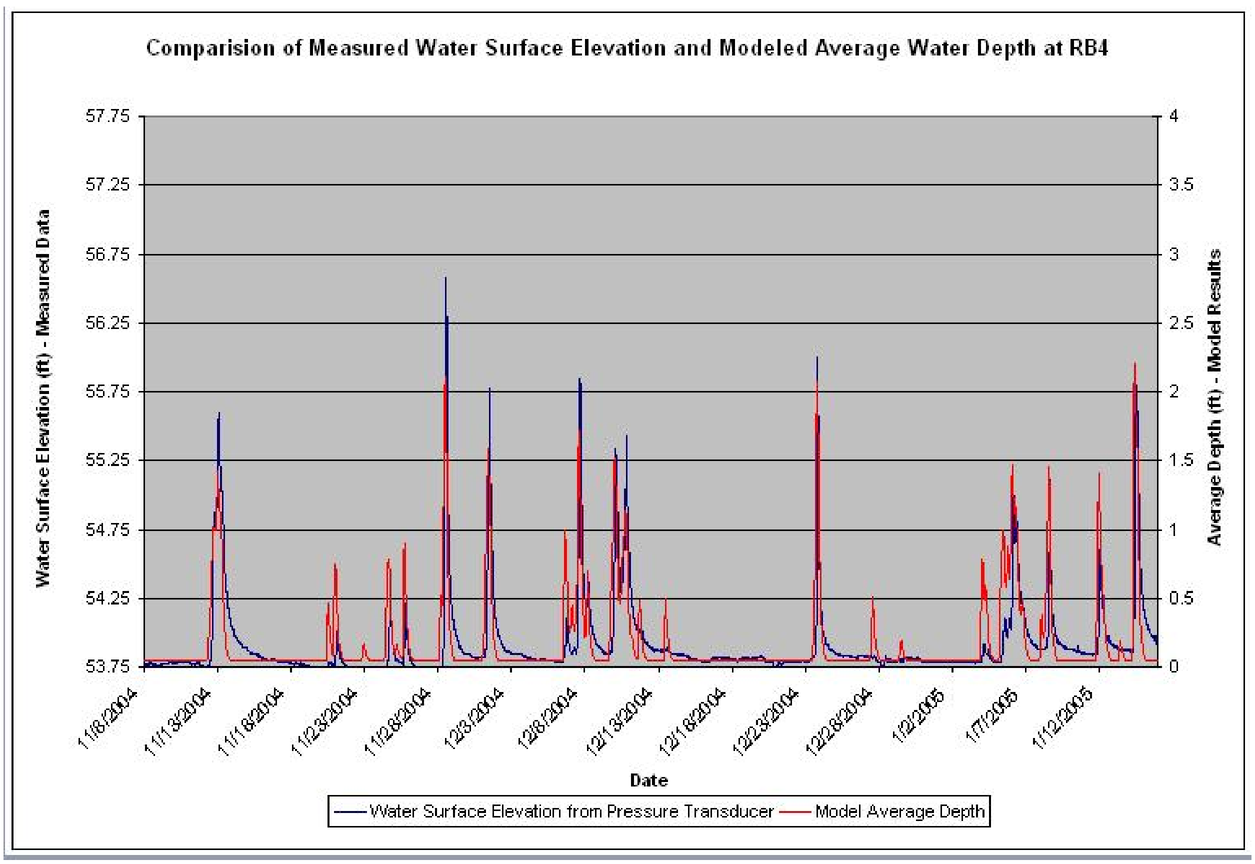
For the Ramanessin DAFLOW model, key parameters in the setup included defining the time step. Through a sensitivity analysis to best define a stable and accurate simulation, a one-hour time step was chosen to simulate flow in the watershed. Other parameters include defining the hydraulic geometry and cross-sectional characteristics to accurately simulate physical properties of the system. TRC Omni used measured cross-section data provided by TRC Site to derive appropriate inputs for the hydraulic geometry of Ramanessin Brook in the DAFLOW model. The final step in the model set up was to define boundary conditions. For this study, the flows for all the sub-basins obtained from the HEC-HMS simulation were used as the flow boundary conditions.

b. WAMIT

The WAMIT (Watershed Model Integration Tool) was developed by TRC Omni to serve as a GIS interface for DAFLOW and to host a number of algorithms for integrating DAFLOW with Water Quality Simulation Program (WASP). WAMIT's GIS interface for DAFLOW allows the user to assign DAFLOW global parameters, local parameters for each node, and time series of flows by selecting the respective node on the map display or on the tree view menu. WAMIT also provides the means of graphic display for the model's inputs and outputs. There are four main algorithms in WAMIT: hydrodynamic file generator, hydrograph separation, GIS based nonpoint source (NPS) pollutant loading model and shear stress analysis routine. Hydrodynamic file generator is primarily used to calculate the velocities and depths the flows obtained from DAFLOW and convert them into a format that can be easily input into WASP, as well as generate the branch network for WASP. The Hydrograph separation routine separates the incremental flow from the sub-basins into base flow and surface runoff. This is useful in generating nonpoint source loads from the base flow and runoff. The NPS loading model generates the loads from the base flows and runoff obtained from the hydrograph separation routine for all the nutrients. It also has the option to create a NPS file that can be directly input into WASP for water quality simulations. Finally, the shear stress analysis routine calculates the shear stress at various cross-sections of the river based on the velocities obtained from the output of DAFLOW. The methodology involved in the hydrograph separation routine and NPS loading model is further described in the GIS based nonpoint source model section and that of the shear stress analysis routine is described below.

Without historic flow data from a USGS monitoring gauge in the watershed, TRC Omni compared continuous depth measurements obtained by pressure transducers installed in the stream at various sampling locations with model results obtained from DAFLOW. This comparison provided validation of the hydrologic model so that model results could be compared with real-time field data. Figure 5 shows a comparison of the continuous depth readings converted to water surface elevation obtained from pressure transducers installed at sampling locations with the average water depths generated by DAFLOW.

Figure 5. Comparison of Measured Water Depth and Modeled Depth at RB4



c. Shear Stress Analysis Routine

The shear stress analysis routine of WAMIT uses the outputs of DAFLOW and calculates the average velocity and shear stress at various locations in the Ramanessin Brook watershed. WAMIT uses the flow and the cross-section area of the stream for each node and time step and calculates the average velocity at different locations (nodes) for each time step using the equation:

$$U = Q / A \tag{1}$$

where U is the average velocity (ft/s), Q (ft^3/s) is the flow and A (ft^2) is the cross-section area at a give location in the river.

The shear stress at various cross-sections is calculated using the following equation (Haestad methods, 2003):

$$\tau = \gamma \ R \ s_f \tag{2}$$

where τ is the shear stress (lbs/ft^2), R the hydraulic radius (ft) and s_f is the friction slope (ft/ft). The friction slope can be estimated from the Manning's equation, which can be rearranged as:

$$s_f = \frac{\eta^2 U^2}{k^2 R^{4/3}} \tag{3}$$

where η is the Manning's roughness coefficient and k is the numerical constant (1.486 for English units and 1.0 for SI units).

C. GIS-Based Nonpoint Source Pollutant Loading Model

1. Hydrograph Separation Algorithm

The hydrograph separation algorithm is necessary to provide an estimate of the individual contribution of surface flow and base flow from each sub-basin. Concentrations of water constituents in base flow and surface flow differ considerably, and so does the proportion of these flows according to sub-basin characteristics. These differences in concentrations and degree of perviousness of a sub-basin directly affect nonpoint source loads. The hydrograph separation algorithm separates the original watershed flows entered in DAFLOW from HEC-HMS into surface flow and base flow. This separation of watershed flows allows the NPS pollutant load calculation as described in the nonpoint source loading section.

The hydrograph separation algorithm is based upon a recursive digital filter method (Nathan, R. J. and T.A. McMahon, 1990). The digital filter method has been widely used for hydrograph separation programs such as USGS's HYSEP (Sloto and Crouse, 1996), and it can be used with one or two filtering parameters. For the one-parameter method, the filter is represented by Equation 16 as shown by Nathan, R. J. and T.A. McMahon, 1990:

$$f_k = \alpha f_{k-1} + \frac{(1+\alpha)}{2}(Q_k - Q_{k-1}) \tag{16}$$

where f_k is the filtered direct runoff at the t time step, f_{k-1} is the filtered direct runoff at the t-1 time step, α is the filter parameter, Q_k is the total stream flow at the t time step, and Q_{k-1} is the total stream flow at the t-1 time step.

The filter parameter represents the recession coefficient of a drainage area. The digital filter for the two-parameter method is given by Equation 17 (Eckhardt, 2005). This method, in addition to the recession coefficient, also uses the BFImax index, which represents the maximum value of long-term ratio of base flow to total stream flow. Equation 17 follows:

$$b_t = \frac{(1 - BFI_{\max}) \times \alpha \times b_{t-1} + (1-\alpha) \times BFI_{\max} \times Q_t}{1 - \alpha \times BFI_{\max}} \tag{17}$$

where, b_t is the filtered base flow at the t time step, b_{t-1} is the filtered base flow at the t-1 time step, BFI_{max} is the maximum value of long-term ratio of base flow to total stream flow, α is the filter parameter, and Q_t is the total stream flow at the t time step.

For the purpose of the Ramanessin Brook watershed model, the two-parameter method was used to separate surface flows and base flows. Default parameters suggested by the literature were initially used for α and BFI_{max} and were later calibrated based on annual ground water recharge, which was estimated using the GSR-32 method and sub-basin characteristics. The value of α used was 0.999 and the value for BFI_{max} used was 0.5.

2. NPS Loading Model

The NPS loading model uses the stormwater Event Mean Concentration (EMC) flow-weighting algorithm to account for differences in surface flow contributions for different land use types. An EMC represents average concentrations of stormwater constituents for a given area based on land use. The model calculates surface runoff and base flow by sub-basin, which lumps distinct source areas with different degrees of perviousness. Since different areas generate different proportions of runoff volume, simply calculating the area-weighted EMC could substantially misrepresent the total load from a sub-basin. Therefore, in order to better represent the relative contribution of areas with distinct land use and soil type, the source area EMCs are flow-weighted based on an approach that uses the Curve Number Method.

The flow-weighting method requires land type EMCs, basin parameters and a value for the representative storm as inputs. EMCs were obtained through stormwater sampling conducted by TRC Omni over the past several years. Drainage areas representing distinct land use types were selected and sampled during storm events. Stormwater data collected by the United States Geological Survey and NJDEP in the Toms River basin were used to supplement TRC Omni data in order to develop land type EMCs for fecal coliform. Six land use classes were represented in this study: residential, commercial, forested, agricultural, barren, and wetlands. Land type EMCs for total phosphorus, total suspended solids, and fecal coliform are provided in Tables 5 and 6 below. Although WAMIT allows EMCs to vary by sub-basin as well as by land use type, the EMCs are assumed to vary only according to land use type for the purpose of the Ramanessin Brook pollutant loading model. It is important to note that stormwater sampling of sub-basins within Ramanessin Brook was not performed for this study; instead, EMCs were estimated based on stormwater sampling of other watersheds in New Jersey with similar land uses.

Table 5. Land Type EMCs for Total Phosphorus and Total Suspended Solids (mg/l)

Land Use Type	Agriculture	Residential	Commercial and Barren	Wetlands	Forest
Total Phosphorus	0.38	0.20	0.16	0.07	0.14
Total Suspended Solids	64.91	38.43	57.01	7.96	7.50

Table 6. Land Type EMCs for Fecal Coliform (#/100ml)

Land Use Type	Forest	Non-Forest (all other land use types)
Fecal Coliform	255	12,075

Basin parameters consist of areas for each land use type within a sub-basin and their respective area-weighted curve number. The assignment of basin parameters starts by defining source areas with unique combinations of land use and soil type. Each of these source areas is assigned a curve number. An area-weighted curve number is then calculated for each land use type. These steps are performed using standard Geoprocessing tools available in ArcView. After the basin parameters are calculated, they can be manually entered in WAMIT or imported using tab-delimited files.

A representative storm is necessary to calculate a percent contribution of flow from areas with different land use types. A value of 1.5 inches was chosen as the representative storm based on rainfall records available for New Jersey. About 94% of the storms in New Jersey are 1.5 inches or smaller, and about 76% of the annual rainfall is delivered in storms of 1.5 inches or smaller.

The flow-weighted EMC for each land use type and for each sub-basin is calculated using Equations 18 and 19. Equation 18 gives the representative surface runoff (f_i) from each land use type (i) (in inches) as a function of the representative storm (P) and the area-weighted average moisture curve number for the respective land use type (CN_i). The flow-weighted EMC ($fEMC_j$) for each parameter (j) is calculated using Equation 19, by dividing the sum of the representative loads from each land use type by the sum of the representative volumes.

$$f_i = \frac{\left[P - 0.2 * \left(\frac{1000}{CN_i} - 10 \right) \right]^2}{\left[P + 0.8 * \left(\frac{1000}{CN_i} - 10 \right) \right]} \tag{18}$$

$$fEMC_j = \frac{\sum f_i * A_i * EMC_{ij}}{\sum f_i * A_i} \tag{19}$$

EMCs for base flow are not assumed to vary by land use type. The flow-weighting EMC method is only applied to calculate loads from surface runoff. EMCs for base flow can be entered directly in WAMIT, and they can vary by sub-basin. Average base flow concentrations for each parameter were calculated and applied for all sub-basins. Baseflow concentrations for total phosphorus, total suspended solids, and fecal coliform were estimated to be 0.05 mg/l, 4.0 mg/l, and 893 colonies/100ml, respectively.

The loads for each sub-basin are calculated based on the flow-weighted EMCs for each parameter and sub-basin, EMCs for base flows, and the surface flows and base flows calculated with the hydrograph separation algorithm. The total volume of water from base flow and the total volume from the surface flow reaching the streams during a flow model time step (one hour) are multiplied by the base flow EMCs and fEMCs, respectively. This multiplication yields the nonpoint source load for each water quality parameter.

V. Watershed Analyses

A. Glauconitic Soil Erosion Potential

The potential for glauconite soil erosion within the Ramanessin Watershed was evaluated using a revised version of the universal soil loss equation (USLE) and available GIS data from Monmouth County GIS Department, NJDEP, USDA-NRCS and USGS.

The universal soil loss equation is defined in Equation 20 as

$$A = R * K * LS * C * P \qquad (20)$$

where A is the loss of soil to streams in tons per acre per year, R is the rainfall erosivity factor (a constant value for this watershed), K is the soil erodability factor, LS is the normalized land slope factor, C is the crop type, and P is the crop management factor. In fundamental terms, the USLE reveals that erosion is most likely to occur in areas of steep slopes, with highly erodable soils, high rainfall, and poor land use management.

Another important factor was the percent glauconite found in each soil. Since the actual glauconite content can vary within a soil type, the percent glauconite is reported in the SSURGO Soil database with a high and a low value. Therefore, a single value for the percent glauconite in a soil was computed by taking the average of the high and low values.

To evaluate the potential for glauconite input to the stream, the USLE was multiplied by the percent glauconite and divided by the crop type factor (C) and crop management factor (P). The resulting parameter is referred to as the relative potential glauconite input, (G), demonstrated in Equation 21:

$$G = (A * \%glauconite) / (C * P) \text{ or}$$

$$G = R * K * LS * C * P * \%glauconite / (C * P) \text{ or}$$

$$G = R * K * LS * \%glauconite \qquad (21)$$

This factor indicates areas with potential of eroding high amounts of glauconite, independent from the land use activity, into waterways. The land use at a particular site will have a great effect on actual soil erosion, but typically, the land use at a particular site changes over time, and this analysis renders G independent of time to some extent.

Each of the USLE factors, with associated attribute data, was entered into the GIS. Spatial overlay operations were applied on these layers to produce the relative potential glauconitic input map shown in Figure 6. The map highlights areas of significant concern that should be managed to reduce erosion and thereby reduce the input of glauconite to the stream. This map should be regarded as a relative picture of areas that need to be considered more carefully than other areas with respect to the particular issue of glauconite. The glauconitic input map was spatially overlaid with a Land Use/Land Cover theme (Figure 7), which shows that in this watershed, potential areas of concern for glauconitic input include urban, agricultural, and forested land uses.

B. Peak Flow and Total Volume Analyses

One of the goals of the modeling analysis was to evaluate impacts of stormwater runoff within the watershed. Using the hydrologic model, relative volumes and peak flows discharged to the Ramanessin Brook from the various sub-watersheds under design storm events were estimated. To understand the relationship of total volume and peak flows to changes in the dynamics of the watershed, we then recalculated stormwater runoff under two different theoretical land use conditions.

The first land use comparison was to recalculate area-weighted composite curve numbers and runoff using a “pre-development” condition. To mimic this condition, the land use data set was manipulated so that all agricultural areas and urban areas were changed to represent a “forested” condition. The composite curve numbers were then recalculated with this modified land use data coverage and the existing soils and entered into the hydrologic model to recalculate stormwater runoff.

The second land use comparison was to attempt to model stormwater runoff under a “build-out” condition in the watershed. To create this modified land use data set, all existing agricultural areas and 50 percent of all forested areas were changed to represent urban land uses. The build-out urban areas were divided into two-thirds residential and one-third commercial to represent the current pattern of urban development in the watershed. As with the pre-development condition, the area-weighted composite curve number was recalculated for each sub-watershed and entered into the hydrologic model to recalculate stormwater runoff.

Figure 6. Relative Potential Glauconite Input

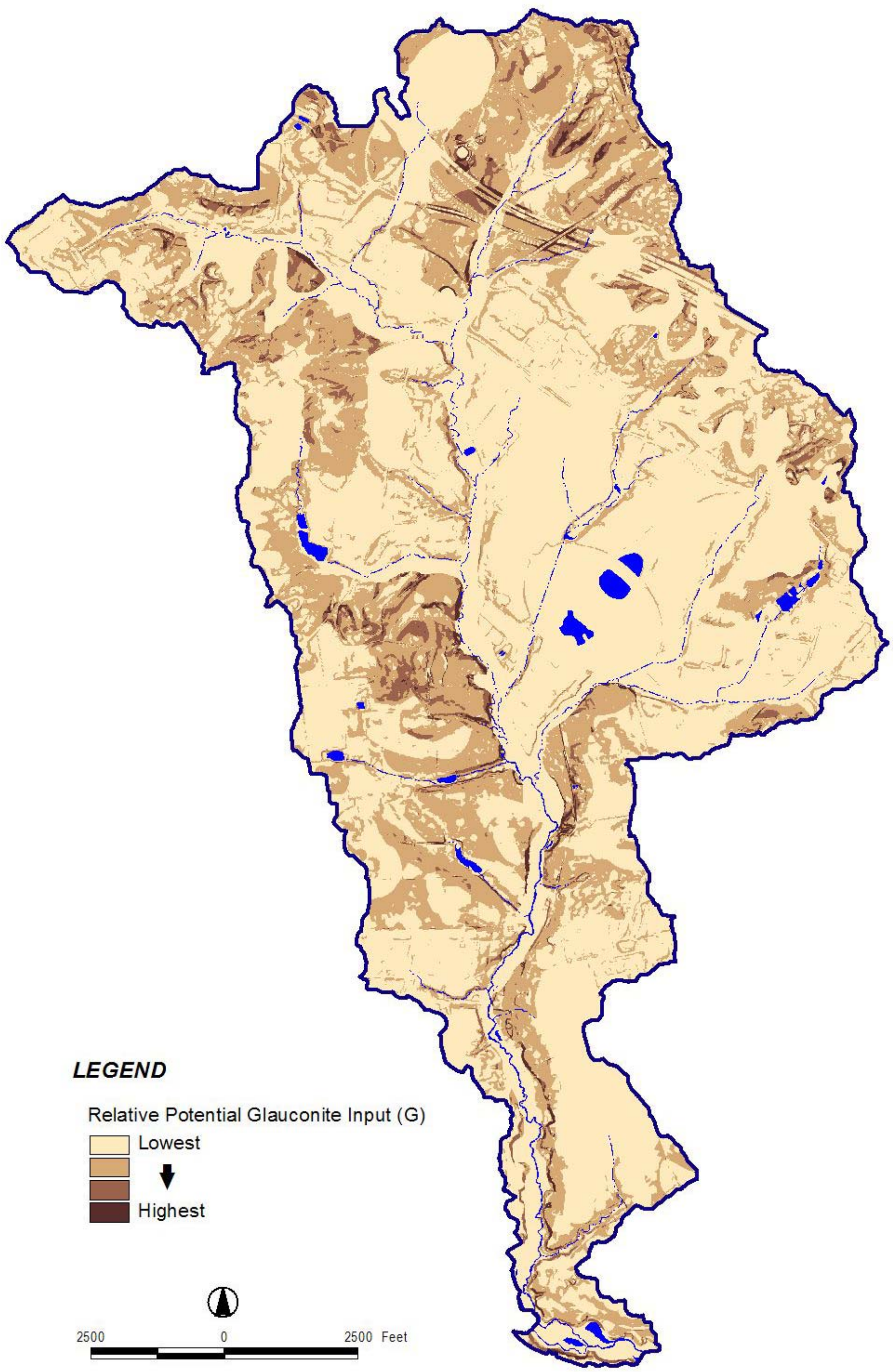
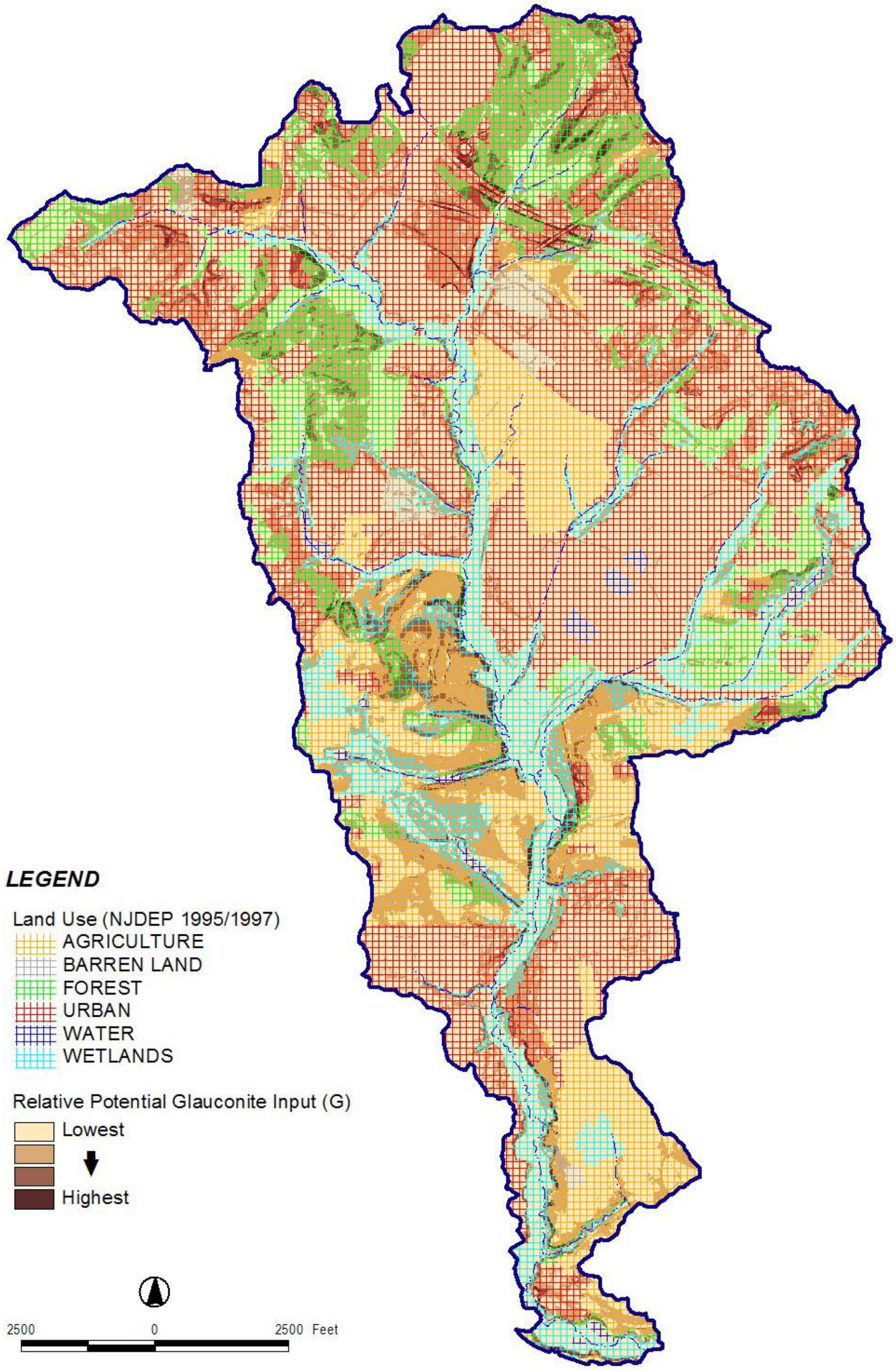


Figure 7. Relative Potential Glauconite Input Overlain with Land Use Land Cover



Using the hydrologic model, the three sets of composite curve numbers representing pre-development, existing, and build-out conditions (Table 7) were used to calculate peak flows and total volume of stormwater runoff from the 1, 2, 10, and 100-year storm events in each of the 20 sub-watersheds identified throughout the basin. It is important to recognize that these analyses do not account for existing or future BMPs, including BMPs that are required for new development under existing stormwater regulations.

Table 7. Sub-Watershed Composite Curve Numbers for Three Land Use Scenarios

Sub-Basin	Pre-Developed Condition	Existing Condition	Build Out Condition
R110W560	64	77	77
R130W20	62	72	74
R140W140	69	74	78
R150W150	66	70	74
R180W180	68	76	78
R240W230	67	74	76
R250W250	65	71	73
R360W320	73	83	84
R370W160	66	75	77
R380W380	74	83	83
R400W220	69	76	78
R40W570	63	69	73
R420W420	79	86	87
R430W410	71	80	80
R470W470	61	72	72
R480W450	72	79	79
R490W490	67	74	74
R510W510	77	83	83
R530W530	71	82	83
R550W550	78	84	84

Peak flows and total runoff volumes were calculated for the four design storms simulated in HEC-HMS. The average percent increase and percent decrease for the various design storms were compared to evaluate the runoff conditions during which land use changes have the most impact on peak flows and runoff volume. The results are mapped in Appendix F and summarized in Tables 8 and 9 below.

Table 8. Comparison of Changes in Peak Flows

DESIGN STORM	AVERAGE PERCENT DECREASE IN PEAK FLOW EXISTING TO PRE-DEVELOPED CONDITION	AVERAGE PERCENT INCREASE IN PEAK FLOW EXISTING TO BUILD-OUT CONDITION
1-year	41%	9.8%
2-year	36%	7.9%
10-year	25%	4.6%
100-year	16%	2.2%

Table 9. Comparison of Changes in Runoff Volume

DESIGN STORM	AVERAGE PERCENT DECREASE IN VOLUME EXISTING TO PRE-DEVELOPED CONDITION	AVERAGE PERCENT INCREASE IN VOLUME EXISTING TO BUILD-OUT CONDITION
1-year	36%	8.4%
2-year	32%	7.2%
10-year	23%	4.8%
100-year	15%	2.9%

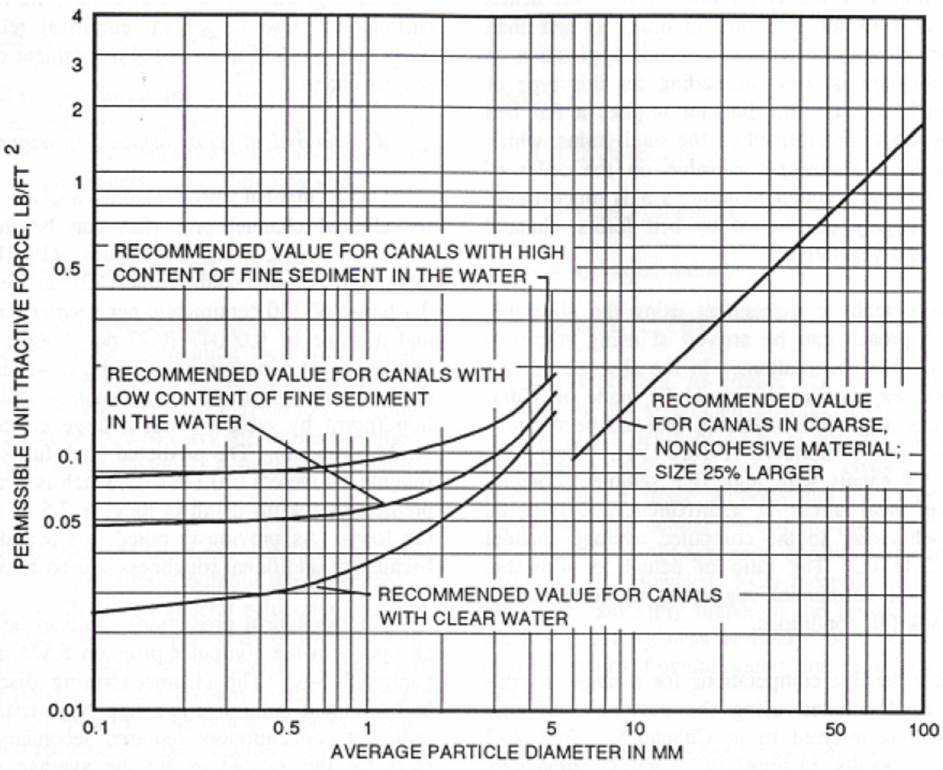
These analyses demonstrate that any changes in watershed land uses that affect runoff have a more significant impact during storms of lower intensities than during storms of higher intensities. The simulations indicate that stormwater and watershed management implemented at a sub-watershed level can significantly impact peak flow rates and volumes during the smaller, more frequent storms that contribute the majority of the rainfall in the State of New Jersey over a given year.

In addition, these analyses demonstrate that land use changes that have already occurred have produced a much larger impact on storm runoff than any changes that might result from future development. Since the analyses performed do not account for BMPs, including those required for new development, they tend to overestimate the impact of new development. Despite this, the analyses show that existing development has had a more profound impact on stormwater characteristics than new development could. As a result, retrofits of existing infrastructure might be more beneficial than additional requirements on new development.

C. Sediment Shear Stress Analyses

The time series of shear stress for different locations in the Ramanessin Brook obtained from the output of WAMIT was compared with the critical shear stress, which depends on the type of sediment in the river bed and the banks. If the shear stress in the river at a particular location is more than the critical shear stress, then the river bed is considered to be eroding under those flow/velocity conditions.

The figure shown below from the USDA-NRCS Stream Restoration Design Handbook (USDA-NRCS, 2005) displays the relationship between the critical shear stress (permissible unit tractive force) for fine-grained soils (D_{75}<6.3mm) and the particle size of the sediment in the river bed. The curve labeled as clear water is for the streams carrying a fine suspended sediment concentration of less than 1,000 ppm. Since all TSS concentrations measured in the Ramanessin Brook were well under 1,000 ppm, the clear water curve was applied.



Allowable shear stress for granular material in straight trapezoidal channels (Lane 1955)

TRC Omni performed analysis of the sediment particles from the bed of Ramanessin Brook and estimated the D_{50} to be 0.3 mm (fine sand). From the above chart, the critical shear stress was estimated to be 0.03 lbs/ft^2 using the curve for the clear water. Note that this critical shear stress does not account for some factors that may be important in localized areas within the stream, such as compaction and vegetative stabilization. In other words, some localized areas within the stream may exhibit more stability than reflected in the critical sheer stress. The shear stress obtained from WAMIT for the six-month simulation (from November 3, 2004 to May 4, 2005) for RB3 and RB5 was plotted along with the critical shear stress and the precipitation from Holmdel weather station, and is shown in Figures 8 and 9, respectively.

Figure 8. Critical Shear Stress, Shear Stress at RB3 Plotted against Precipitation

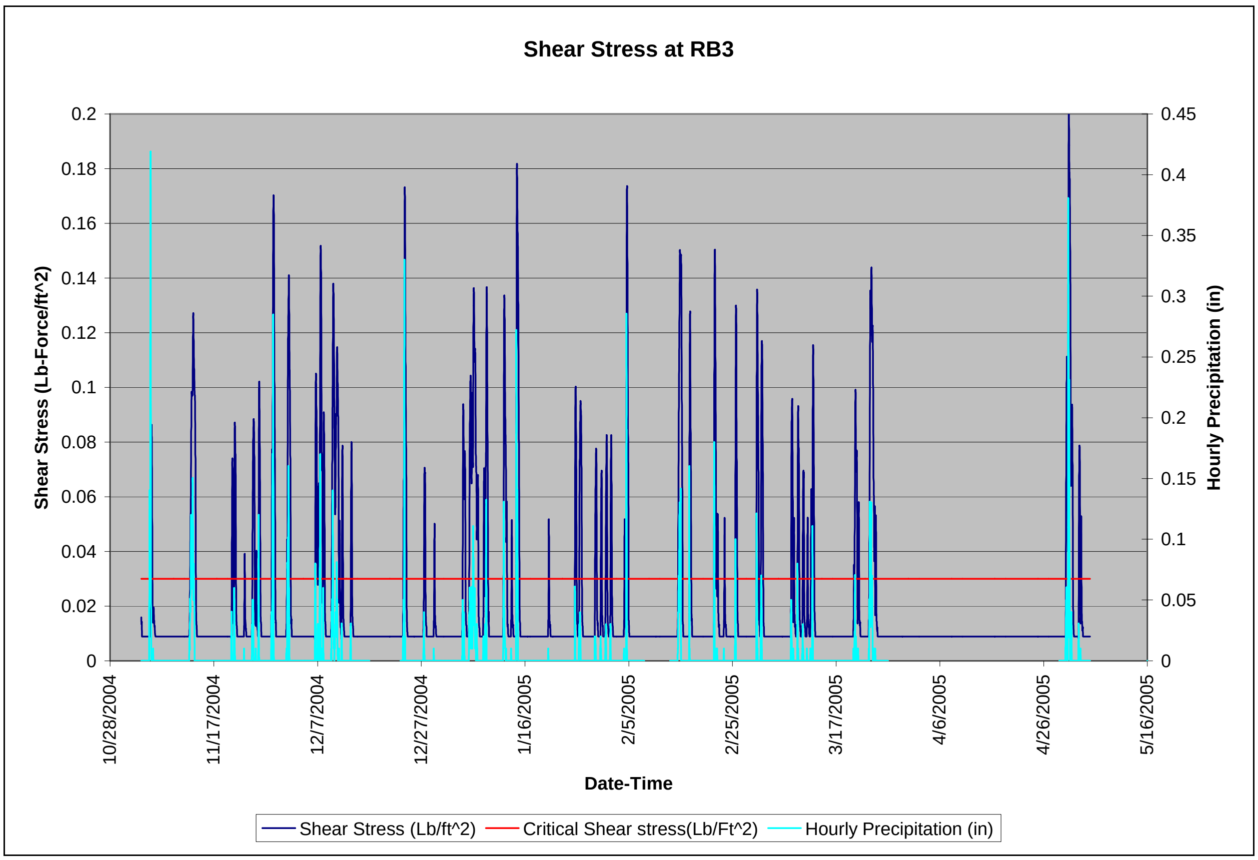
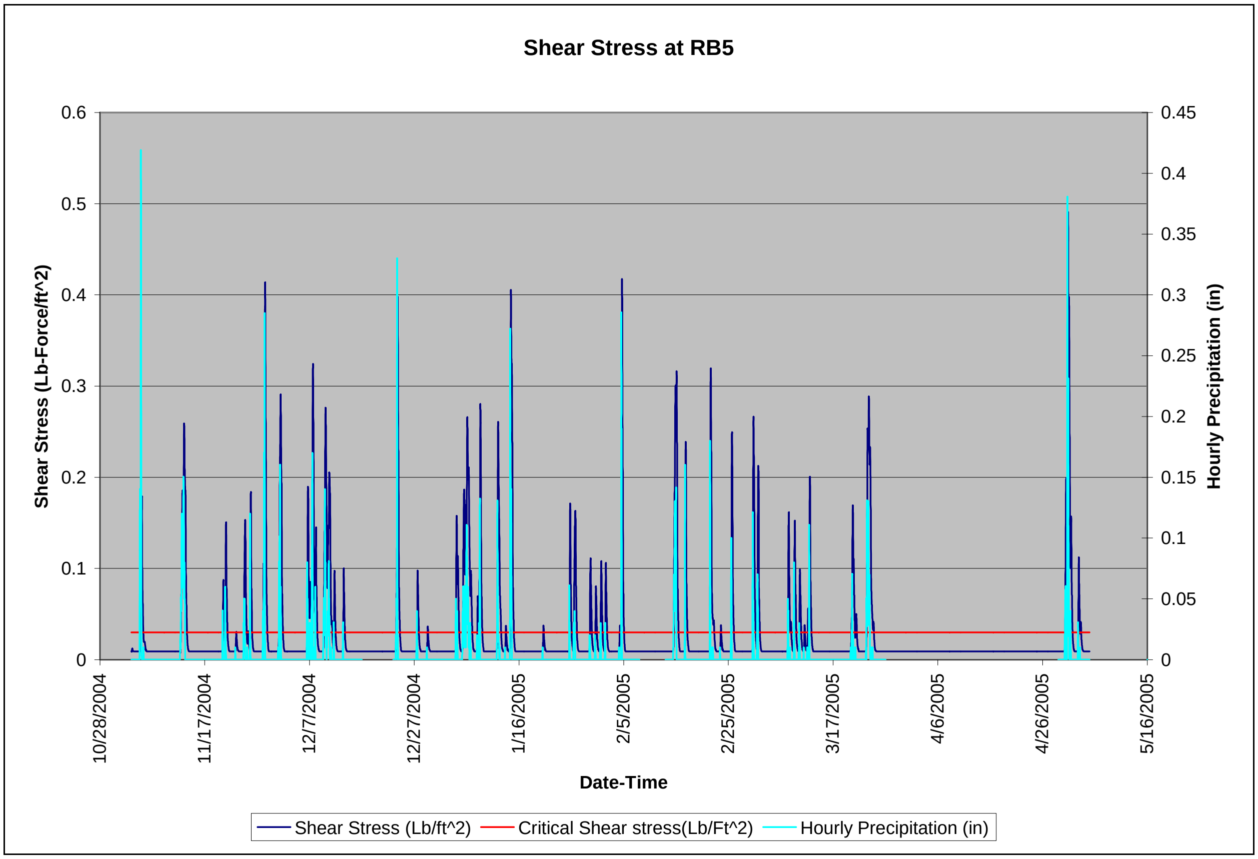


Figure 9. Critical Shear Stress, Shear Stress at RB5 Plotted against Precipitation



The above figures demonstrate that the shear stress at all the sampling stations in the Ramanessin Brook is considerably higher than the critical shear stress during nearly all the rainfall events. From this, we can conclude that the river bed of Ramanessin Brook is eroding during most rainfall events. This conclusion is supported by anecdotal field observations made by our staff, such as stream bank erosion and the burial of pressure transducers in stream beds after storm events.

In order to analyze further the erosion in the river, the 1-year and 2-year SCS hypothetical storm events were used to estimate the total shear stress over a 24-hour period at all the cross-sections in the river and were compared with the total critical shear stress over a 24-hour period. Figures 10 and 11 show the comparison of the total shear stress and total critical shear stress at all the cross-sections (nodes) in the Ramanessin Brook for 1-year and 2-year SCS hypothetical storm events, respectively.

Figure 10. Total Shear Stress and Total Critical Shear Stress for 1-Year Storm Event

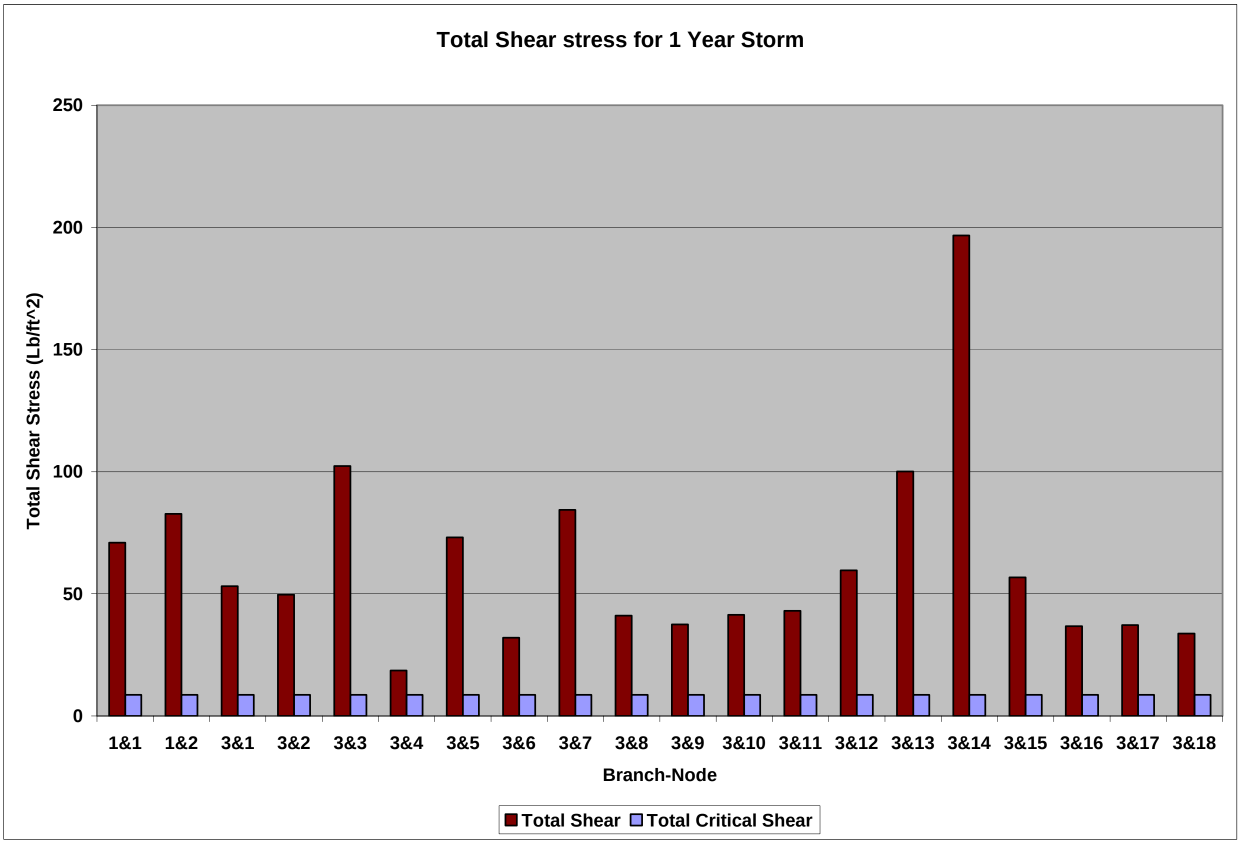
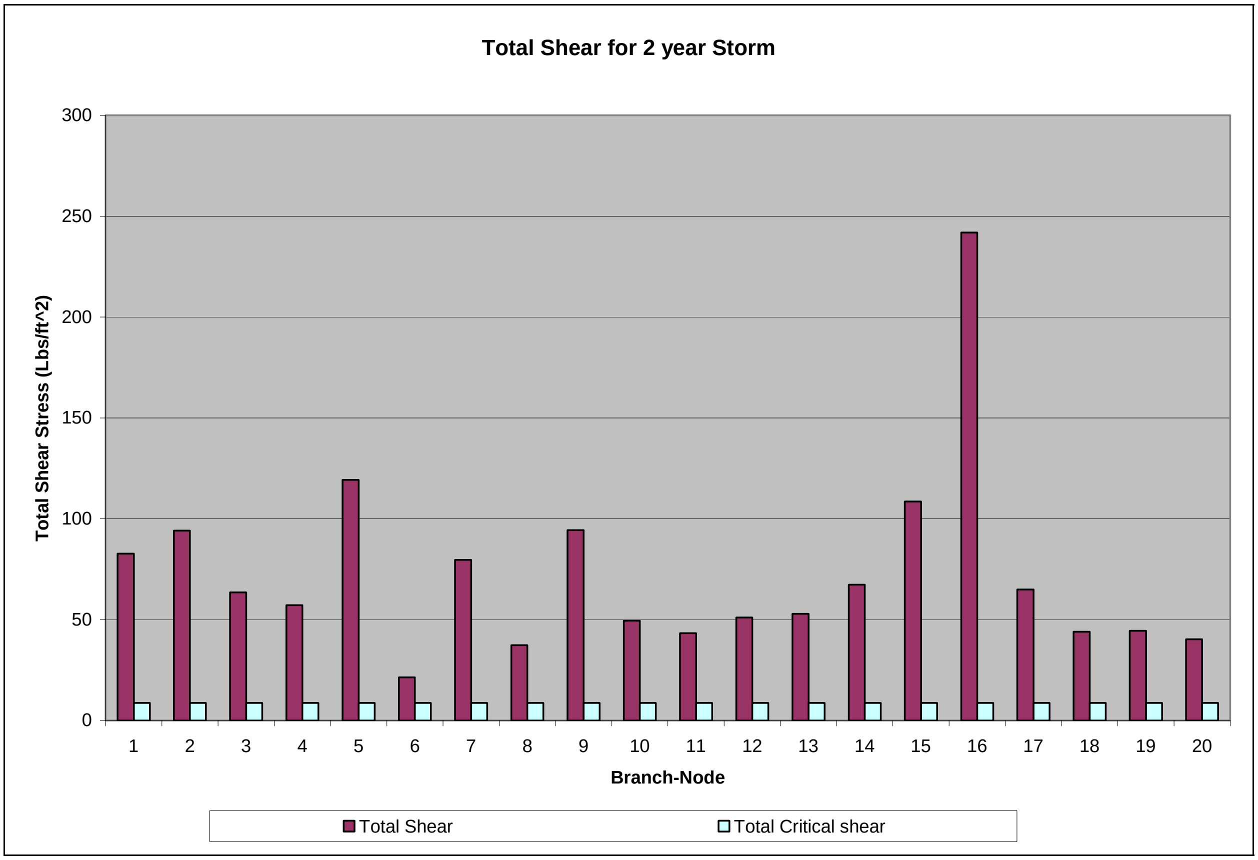
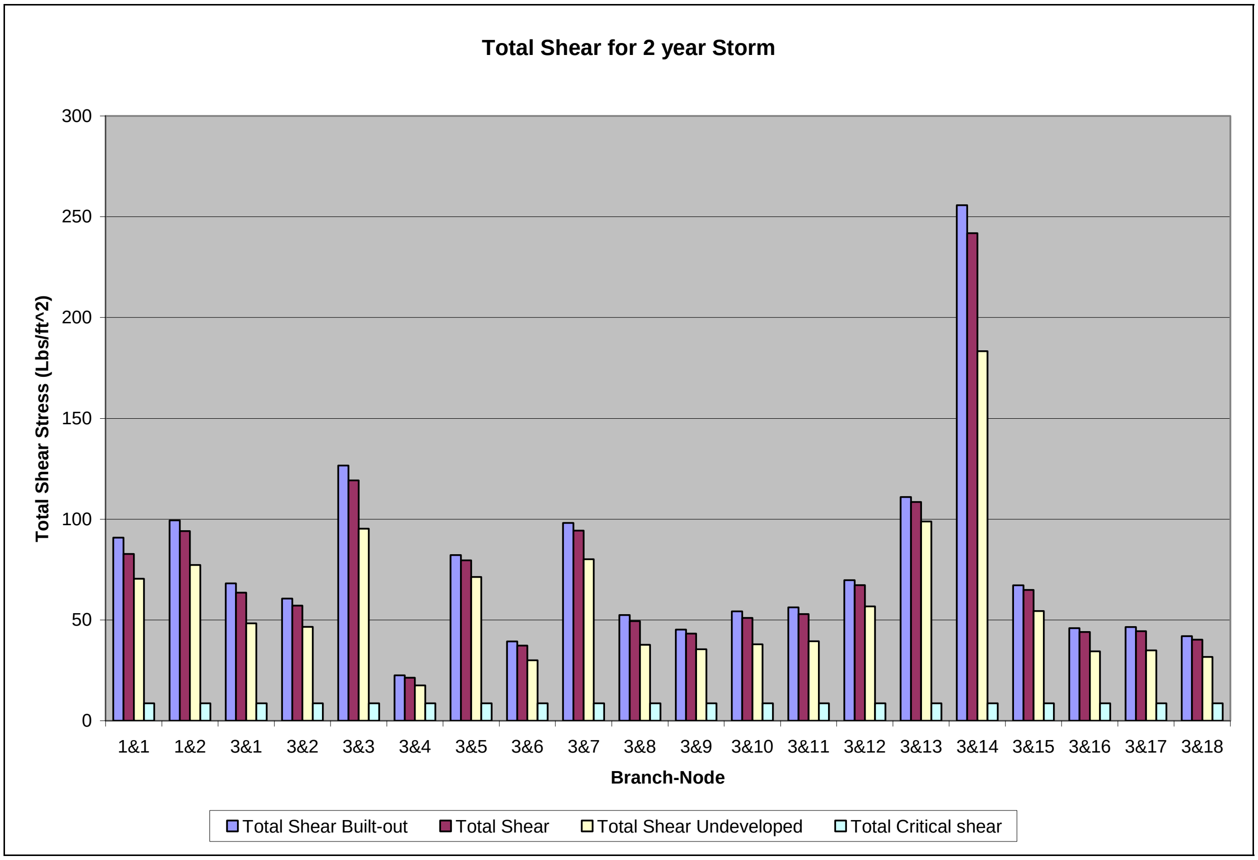


Figure 11. Total Shear Stress and Total Critical Shear Stress for 2-Year Storm Event



Figures 10 and 11 show that all sections of the stream are eroding during 1-year and 2-year hypothetical storms. In order to see if the implementation of stormwater reduction best management practices (BMPs) would reduce the erosion of the river bed under smaller storms, a comparison of the total shear stress with total critical shear stress was done for existing, built out, and undeveloped condition in the whole watershed. Figure 12 shows the comparison of the total critical shear stress to the total shear stress for the existing, built out, and undeveloped conditions of the watershed for a 2-year hypothetical storm event. From the below figure it is clear that the stream bed is eroding under all conditions of rainfall and the stormwater reduction BMPs would not prevent the stream bed from eroding.

Figure 12. Total Critical Shear Stress and Total Shear Stress for Existing, Built-Out and Undeveloped Conditions for a 2-Year Hypothetical Storm Event



D. Pollutant Loading Analyses

1. Total Load Analyses

Using the nonpoint source pollutant model described previously, the total loads for TP, TSS, and FC were estimated for each sub watershed based on the total volume of runoff during 2-year storm events. Maps showing the total estimated loads and normalized loads (per area) are provided in Appendix F. These maps illustrate the sub-watersheds that contribute the most pollutants to Ramanessin Brook. Also provided in Appendix F are maps showing total estimated loads during 2-year storm events for pre-development, existing, and build-out conditions. These maps illustrate the impact of land use changes on pollutant loading to Ramanessin Brook.

2. Ratio of Observed to Estimated Loads

In order to evaluate the contribution of runoff pollutant loads versus instream pollutant load from stream bank erosion, the estimated daily runoff loads were compared with measured loads (expressed as daily load) during sampling events for a six-month simulation. In theory, the ratio of measured instream load to estimated runoff load would be 1.0 if the estimated load accounted for the entire load and if pollutant attenuation in the stream were not important. Because of the uncertainty associated with the load estimate and instream attenuation, the actual ratio is not significant. However, an evaluation of how the ratio between observed and estimated loads changes from upstream to downstream can be used to assess the importance of instream erosion as a pollutant source. Figures 13, 14, and 15 show the average ratio of observed daily loads to estimated daily loads from upstream to downstream for total phosphorus, total suspended solids, and fecal coliform, respectively.

The ratio of observed load to predicted load increases substantially from upstream to downstream for both TP and TSS. This means that runoff can account for less of the observed load at downstream locations than upstream locations. This pattern indicates that instream erosion is likely an important source of TP and TSS. The magnitude of the ratio, while not very accurate, indicates that instream erosion is in fact far more important than runoff loads for TP and TSS. In other words, the observed loads of TP and TSS cannot be easily explained by runoff contributions. Fecal coliform results show no such pattern, meaning that these results do not indicate that instream erosion is an important source of fecal coliform in Ramanessin Brook.

Figure 13. Total Phosphorus Ratio of Observed to Predicted Loads

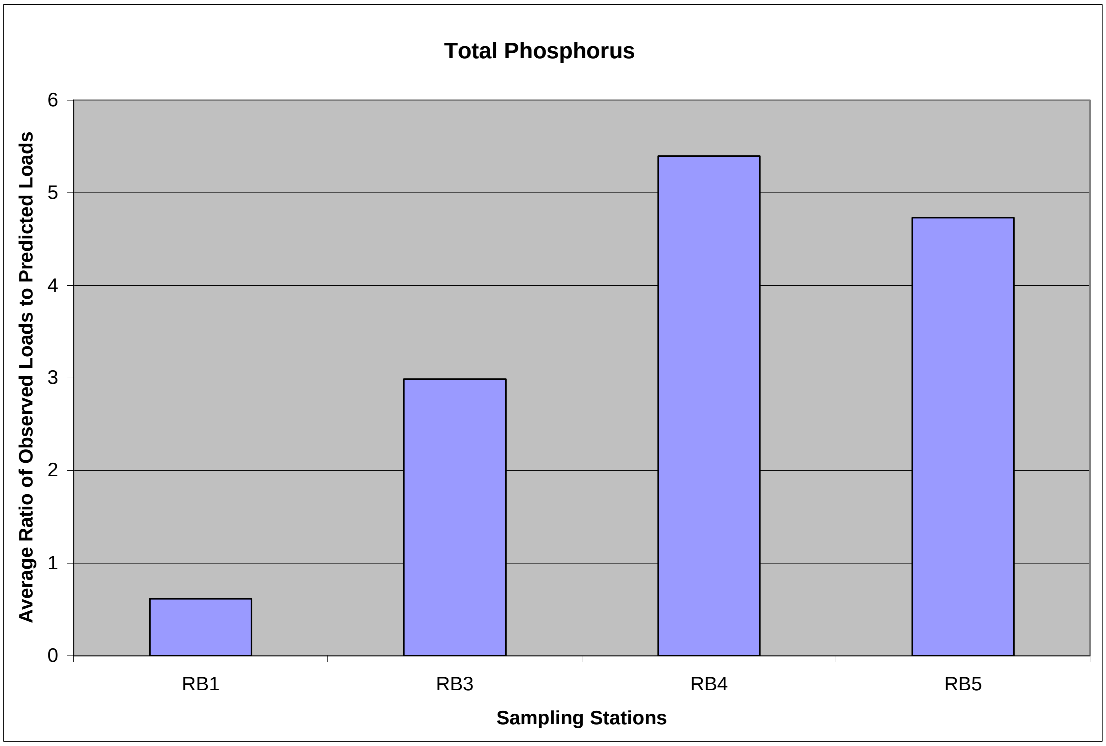


Figure 14. TSS Ratio of Observed to Predicted Loads

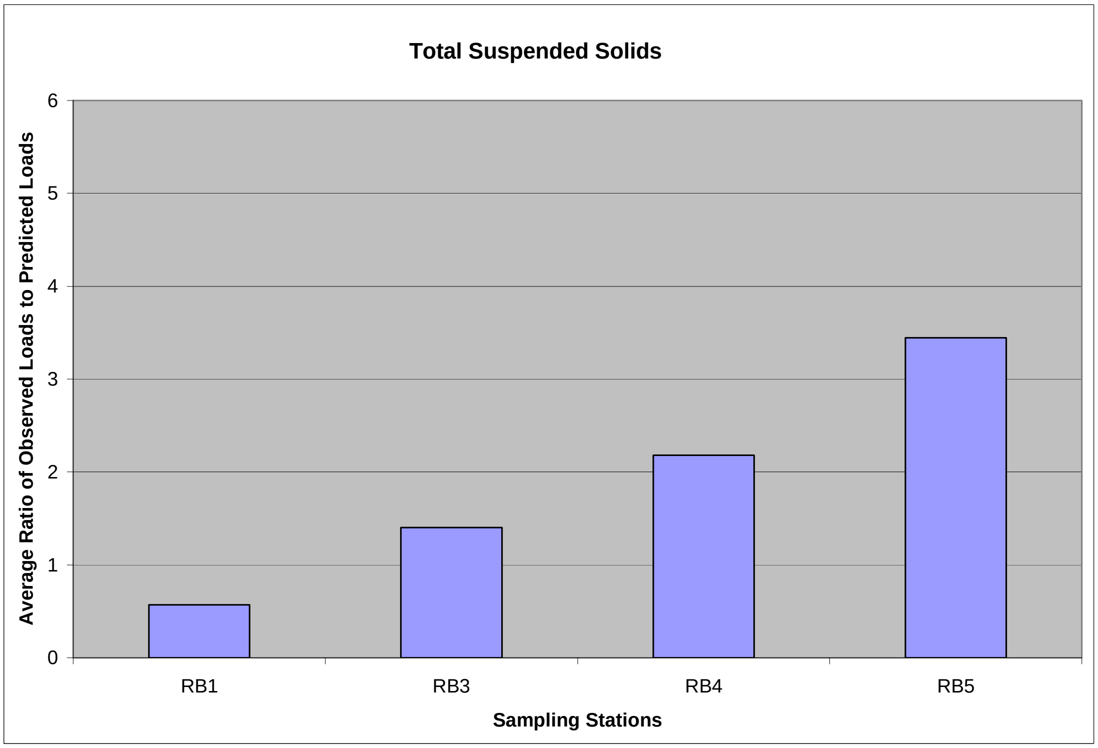
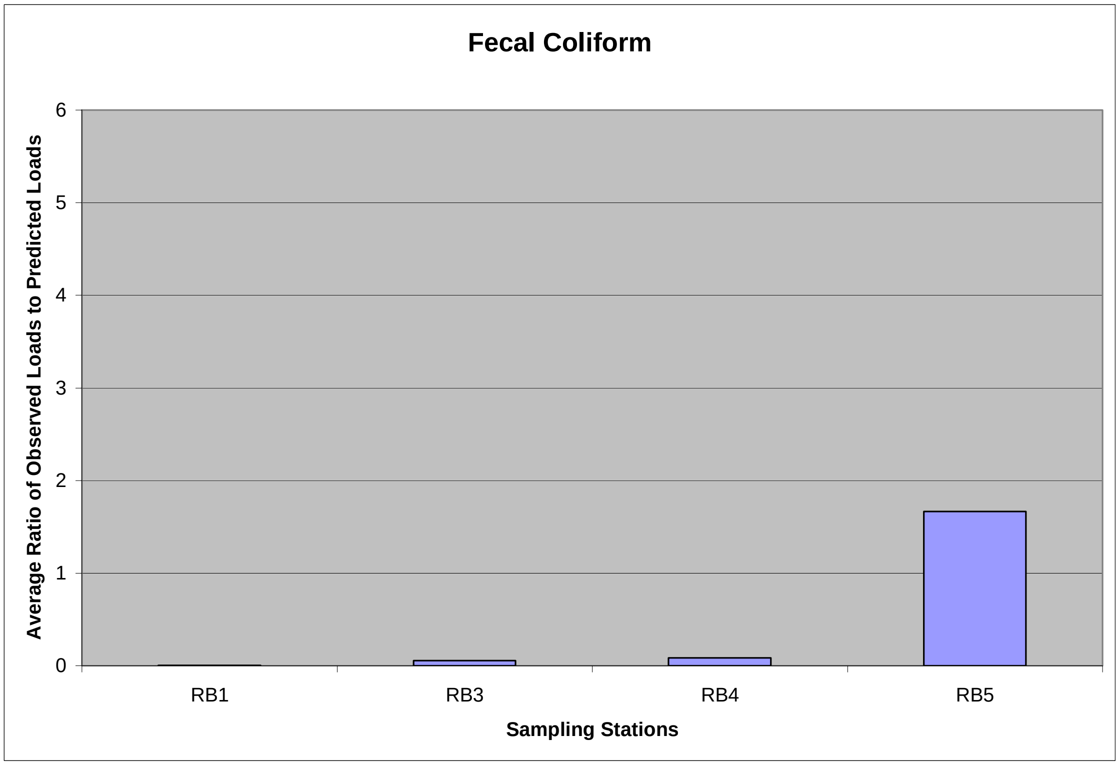


Figure 15. Fecal Coliform Ratio of Observed to Predicted Loads



E. Water Quality Assessment

1. Phosphorus

a. Results

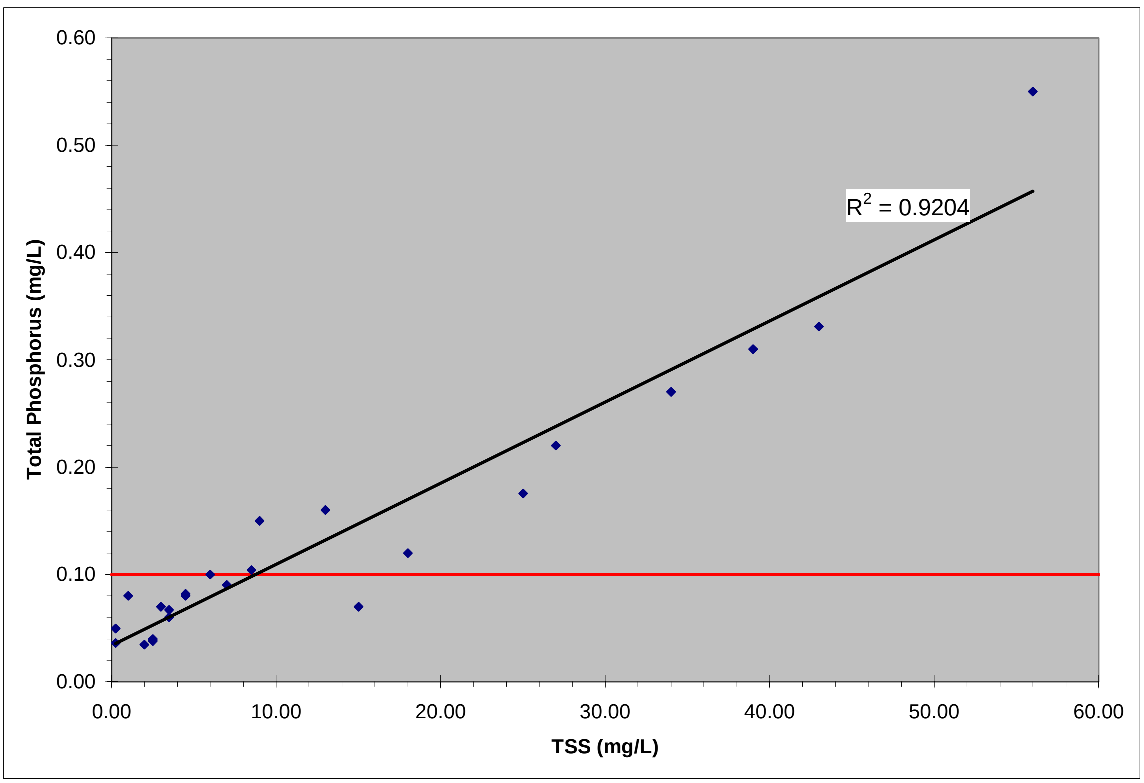
Table 10 shows the average phosphorus at each sampling station for all events and the number of times the result exceeded the 0.10 mg/l criterion.

Table 10. Total Phosphorus Sampling Results

SAMPLING LOCATION	AVERAGE OF ALL DATA	NO. of RESULTS ABOVE 0.10 mg/l
Base	0.036	0 of 7
RB1	0.055	3 of 24
RB2	0.147	7 of 24
RB3	0.126	8 of 24
RB4	0.155	11 of 24
RB5	0.137	10 of 24

At all stations, strong positive and linear correlations were observed between total phosphorus and the following three parameters: total suspended solids (R^2 = 0.78), iron (R^2 = 0.74), and turbidity (R^2 = 0.76).[1] These relationships were even more strongly linear downstream at stations RB4 and RB5. For example, Figure 16 shows the linear relationship observed between total phosphorus and total suspended solids at RB5. The red line shows the instream phosphorus criterion of 0.1 mg/l, which is exceeded only when total suspended solids is higher than 15 mg/l. Sediment was consistently high in phosphorus, with an average total phosphorus concentration of 144 mg/kg in all sediment samples.

Figure 16. Total Phosphorus vs. TSS at RB5



The dissolved reactive phosphorus data for each event is relatively low and consistent across sampling locations. The average of all the dissolved ortho-

[1] Sample results from March 23, 2005 were excluded from the linear regressions. This high-flow event yielded very high outliers for TSS, iron, and turbidity that masked the strength of the overall linear regressions somewhat. However, samples from this date at all locations also showed positive linear regressions between phosphorus and these three parameters (R^2 = 0.66, 0.78, 0.75).

phosphate results is 0.028 mg/l for all sampling locations. It is also important to note that iron was extremely high, with a range from 0.26 mg/l to 15.4 mg/l (outliers of 44.1 mg/l and 37.6 mg/l were observed during a high-flow event on March 23, 2005 at stations RB2 and RB3). The average iron concentration is 2.40 mg/l for all sampling locations. In addition to the interactions in the stream between iron and phosphorus, iron is known to interfere with laboratory analysis of dissolved reactive phosphorus (bias high).

b. Summary

The water quality results, sediment quality results, and pollutant loading analyses for phosphorus all point to the importance of erosion of glauconitic soils, both from the watershed and in the stream itself, as a major source of phosphorus in the Ramanessin Brook. Phosphorus is highly correlated with TSS, iron, and turbidity. These correlations get stronger at downstream locations. Furthermore, the ratio of observed instream loads to estimated runoff loads increases dramatically at downstream locations. In other words, the observed levels of phosphorus at downstream locations cannot be fully explained by runoff loads. All of these observations show the importance of instream sediment erosion as a major source of phosphorus.

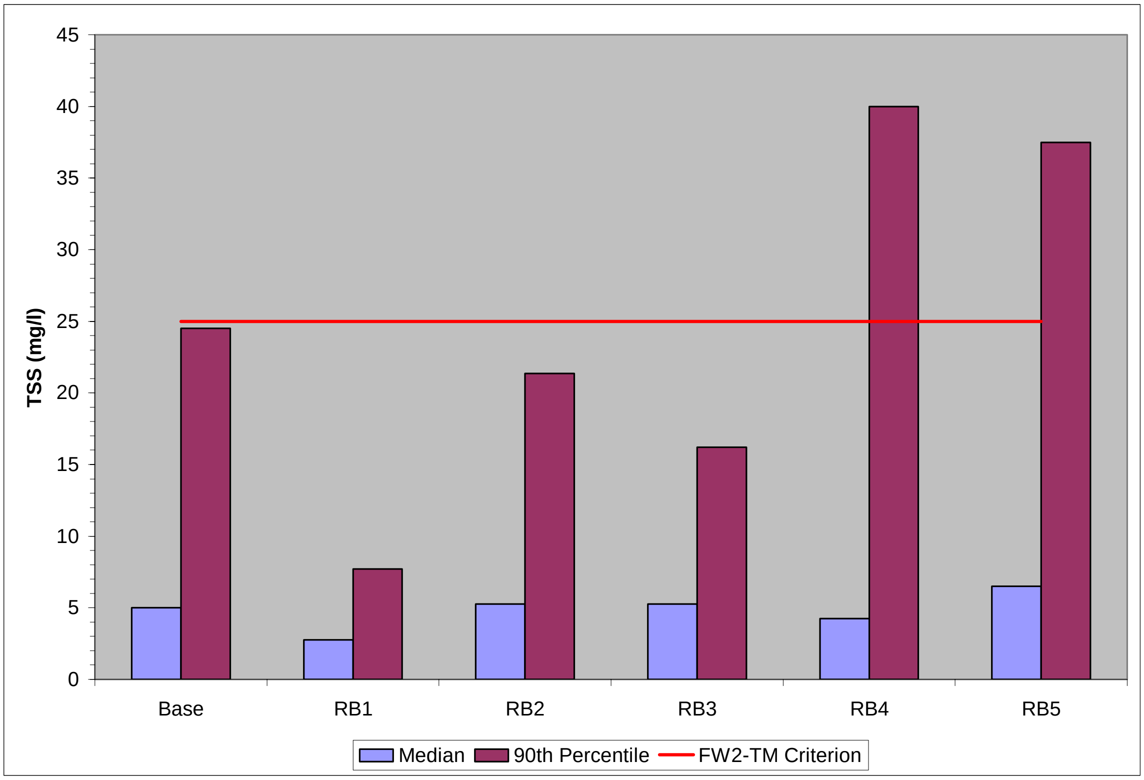
The fact that the eroded sediment is rich in glauconite alters the impact of phosphorus in the stream. Iron-rich sediments from glauconitic soils bind phosphorus to suspended particles, rendering the phosphorus unavailable for plant and algal growth in the stream. While this study did not evaluate productivity indicators specifically, the stream was qualitatively observed to be very low in plant and algae productivity despite having quite high phosphorus concentrations. Indeed, because of the high iron concentrations in the stream, the chemical binding of phosphorus to iron will prevent excessive productivity in the stream regardless of phosphorus concentrations. The chemical binding reaction is simply faster than biological uptake.

2. Suspended Solids

a. Results

The mean and 90th percentile value for total suspended solids (TSS) at each station is shown in Figure 17, along with the applicable surface water quality criterion of 25 mg/l[2] shown as a red line. More than 10 percent of the samples at downstream locations (RB4 and RB5) exceed the criteria.

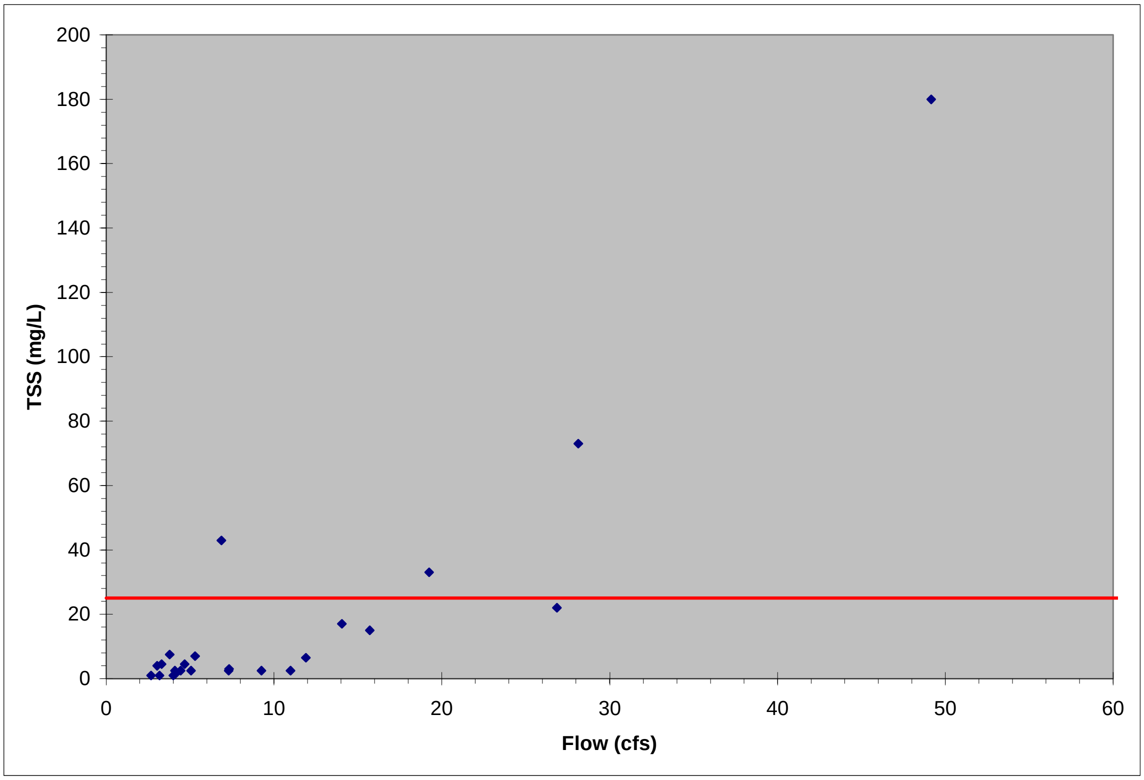
Figure 17. Total Suspended Solids



As expected, TSS is strongly related to flow, as shown in Figure 18 below for Station RB4. Exceedances of the TSS criterion at this location are generally observed when the flow exceeds 20 cfs.

[2] Ramanessin Brook is classified by NJDEP as freshwater trout maintenance (FW2-TM).

Figure 18. TSS vs. Flow at RB4



b. Summary

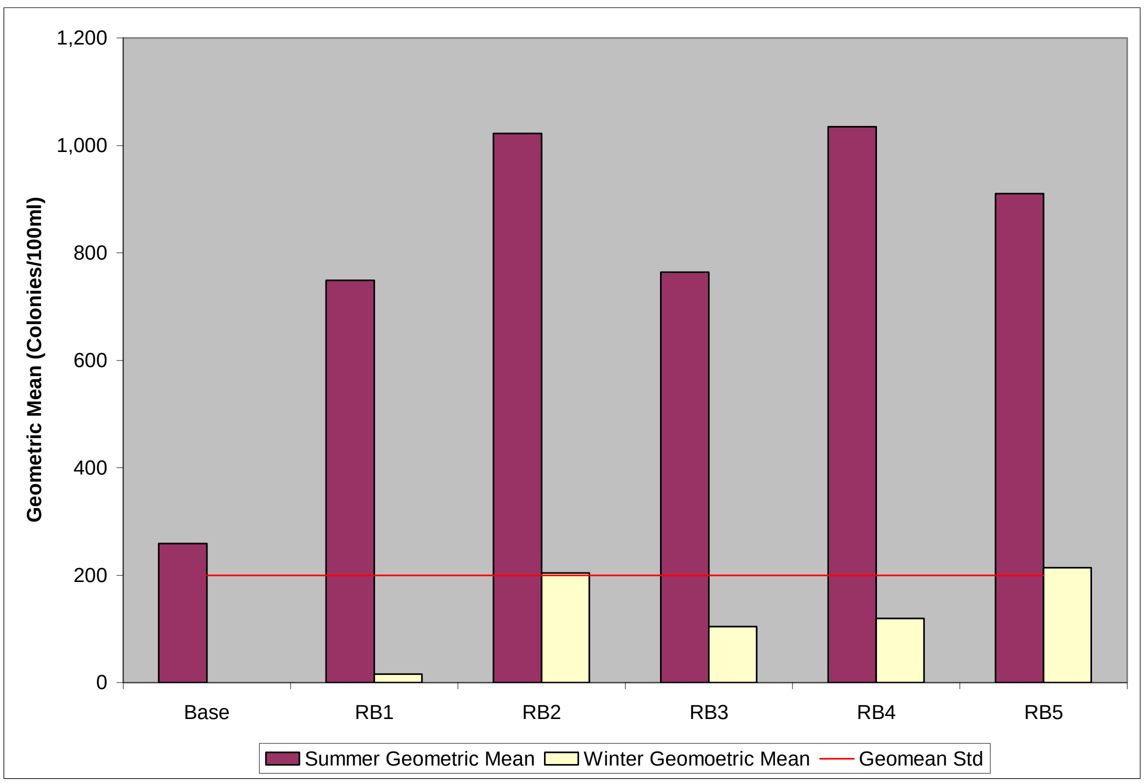
TSS is highly correlated with flow. In fact, during high flows, TSS exceeds FW2-TM criterion in downstream areas. In addition to impacts due to high TSS concentrations within the stream, TSS load is important because Ramanessin Brook flows into Swimming River Reservoir. Since TSS load is equal to the stream flow multiplied by TSS concentration, the high concentrations of TSS during higher flows increases the TSS load dramatically. Furthermore, the ratio of observed instream loads to estimated runoff loads increases dramatically in downstream locations. In other words, the observed levels of TSS at downstream locations cannot be fully explained by runoff loads. Based on all these observations, instream erosion represents a major source of TSS in terms of both concentration and load.

3. Fecal Coliform

a. Results

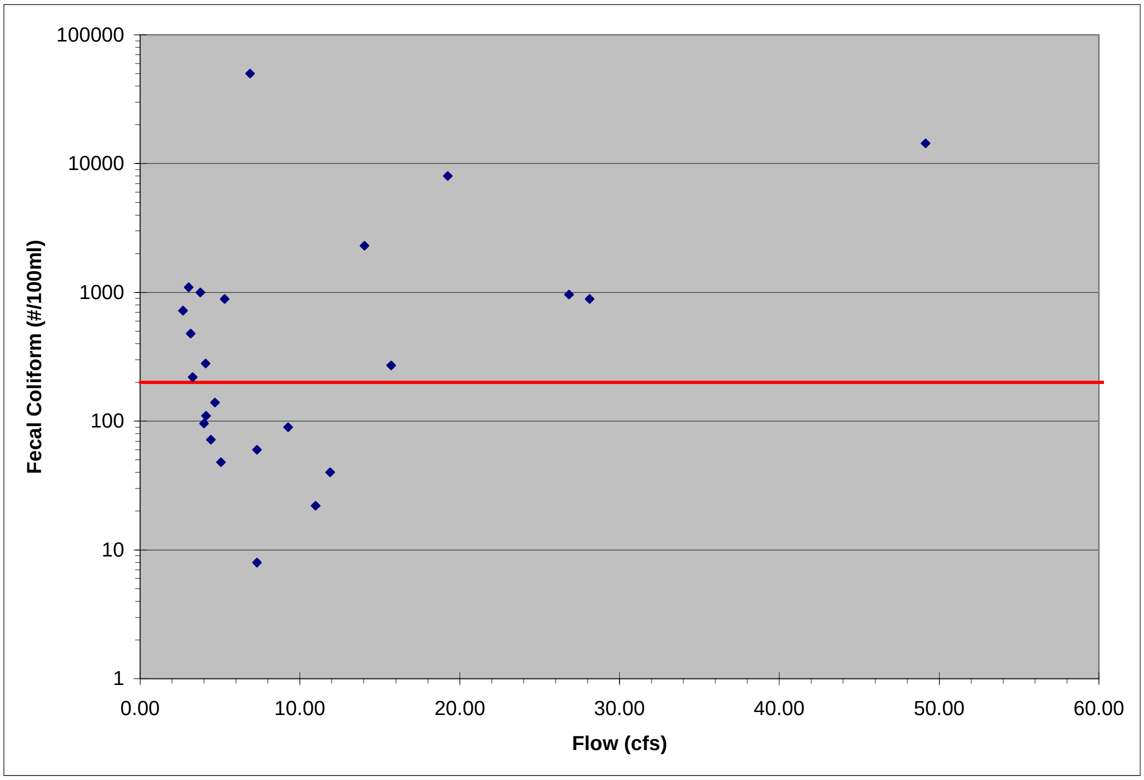
Fecal coliform is a bacterial indicator of pathogenic contamination. These bacteria are present in large numbers in the feces and intestinal tracts of humans and other warm-blooded animals, and can enter water bodies from human and animal waste. Results of fecal coliform analyses for each sampling station are shown in Figure 19. Winter and summer samples were separated because of the strong seasonal trend observed. For comparison, the 30-day geometric mean criterion (200 colonies/100ml) is shown as a red line. Summer geometric means exceed the 200 colonies/100ml criterion at all locations including the reference station (BASE), although the values within Ramanessin Brook are much higher than the reference station.

Figure 19. Fecal Coliform Results



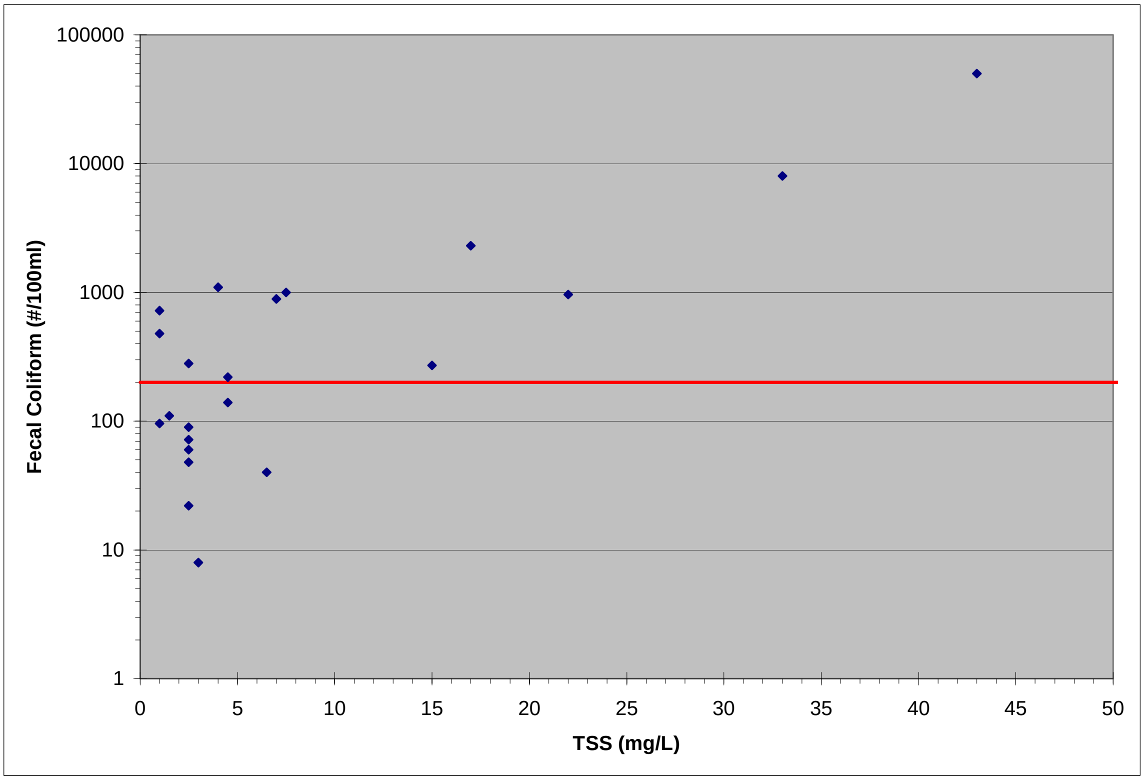
The fecal coliform results show an inverse relationship with flow under low flow conditions, indicating that fecal coliform concentrations increase as flow decreases. Such a pattern indicates that small flow increases due to changes in baseflow decrease the fecal coliform concentrations due to dilution of relatively constant loads. Interestingly, under higher flow conditions, fecal coliform concentrations increase with increasing flow, indicative of runoff-based loads. This bi-modal relationship with flow is best seen at RB4 in Figure 20.

Figure 20. Fecal Coliform vs. Flow at RB4



As flow increases under high flows, the TSS concentration also increases, as shown at RB4 in Figure 21. This is expected, since TSS is strongly related to flow. It indicates that runoff loads of fecal coliform are particulate in nature. Both bank and bed sediment samples were extremely low in fecal coliform (<10 and 10 colonies/gram, respectively). Note that as per the QASP, only two soil samples were analyzed for fecal coliform.

Figure 21. Fecal Coliform vs. TSS at RB4



The ratio of the fecal coliform to fecal streptococci (FC/FS) varies for different animals. Ratios greater than 4.0 indicate human sources, while ratios less than 0.8 indicate animal sources. Ratios between 0.8 and 4.0 are considered inconclusive, or indicate contamination from both human and animal species. Because survival rates of these organisms vary in different environments, this ratio is not always reliable, but can be useful as a preliminary indicator, especially in a watershed such as Ramanessin Brook that receives no point source inputs from municipal sewage treatment plants. The FC/FS was greater than 4 only twice, at different sample stations on different days. The FC/FS ratio was less than 0.8 a total of five times for all sampling locations and was not specific to low, ambient, or high flow events. Of the twenty-two samples with fecal coliform concentrations over 200 colonies/100ml and for which fecal streptococcus was also measured, nineteen had FC/FS values between 0.8 and 4.0. Unfortunately, the FC/FS results did not yield much insight into whether the sources were human in origin or not.

b. Summary

Samples taken during the summer have much higher fecal coliform concentrations than those taken during the winter. In fact, the 30-day geometric mean criterion appears to be exceeded at all sites, including the reference station, during the summer. However, the fecal coliform concentrations at the stream locations are much higher than at the reference location. High levels of bacterial contamination are observed at both low and high flows. During low flows, fecal coliform concentration increases as flow decreases. This indicates a constant load that gets diluted by baseflow, such as failing septic discharges or perhaps direct deposition by resident waterfowl or other wildlife. During high flows, fecal coliform concentration increases as flow increases. This clearly indicates high runoff loads being delivered to the stream. Fecal coliform appears to be correlated with TSS during high flows when TSS is high.

While only two sediment samples were analyzed for fecal coliform, no bacteria was observed in one and in the second, bacteria was only observed at the minimum detection limit of 10 colonies/gram. Furthermore, the ratio of observed instream loads to estimated runoff loads does not increase substantially at downstream locations, and is generally less than one. In other words, the observed fecal coliform levels may be explained based on runoff and baseflow loads. This study did not find any evidence for the proposition that fecal contamination is caused by erosion of bacteria-rich sediments.

VI. Recommendations

The following lists contain recommendations based on the watershed sampling, watershed modeling, and watershed analyses performed for this study.

A. Storm Water Quantity and Velocity Controls

- Apply hydraulic model to regional stormwater planning for Ramanessin Brook – a HEC-RAS model was set up for Ramanessin Brook and can be applied to evaluate flooding within the watershed during various storm events.

- Focus stormwater improvements on small storm retrofits in most sensitive areas – the hydraulic modeling analyses performed during this study (Appendix F) identify the most sensitive areas for pollutant loading as well as instream erosion (shear stress analysis). The modeling also demonstrates the potential impact of watershed improvements on runoff characteristics from small storm events, and the relative importance of existing development.

B. Fecal Coliform Mitigation

- Fecal coliform mitigation should focus on runoff and baseflow – the results of the study indicate that both runoff and baseflow are important sources of fecal coliform. The study provides no support for the premise that instream erosion of bacteria-rich sediments represents an important source of fecal coliform in Ramanessin Brook.

- Follow-up this study with local stormwater and baseflow monitoring – bacterial source trackdown should focus on localized monitoring within the watershed to locate the geographic sources of baseflow and runoff loads.

C. Phosphorus Mitigation

- Phosphorus export to reservoir is far more important than instream impacts – the results of the study indicate that phosphorus is not exerting a water quality impact within Ramanessin Brook due to the influence of iron. Phosphorus is tightly associated with sediments and is rendered unavailable to plants and algae within the stream.

- Consider engineered sediment abatement at outlet of Ramanessin Brook – phosphorus-rich sediments are delivered through Ramanessin Brook to Swimming River Reservoir. Instream erosion represents a major source of phosphorus (and sediments), and the soils within this watershed will erode substantially regardless of any stormwater improvements that are implemented. Therefore, in order to mitigate the introduction of phosphorus-rich sediments into Swimming River Reservoir, engineered sediment abatement structures should be considered for the outlets of Ramanessin Brook and other similar inlet tributaries.

D. Next Steps

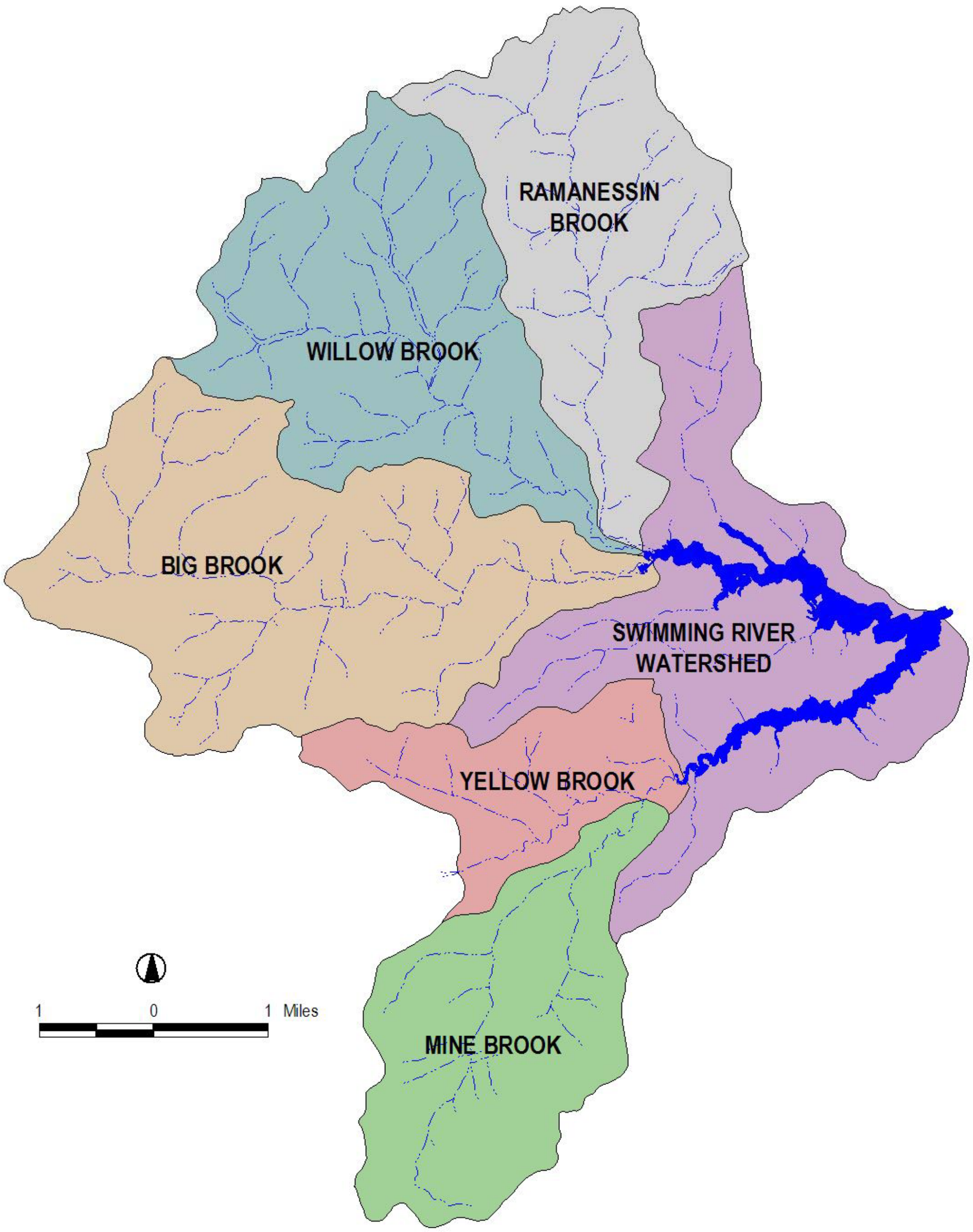
1. Ramanessin Brook Stormwater Improvements

The results of the study indicate the smaller more frequent storm events (less than 2 inches of rainfall) as causing the most significant chances in stream flows and that the greatest increases in watershed runoff are likely to have already occurred with the existing land use changes in the watershed. In addition, given the newest stormwater regulations, any new development will have to strictly comply with peak flow and stormwater volume controls to maintain existing hydrologic patterns to the greatest extent practical. With this understanding, stormwater management planning in the Ramanessin Brook watershed should focus on clearly mapping and identifying existing infrastructure and determining methods to disconnect existing development from stormwater conveyance systems during these smaller storms where possible and practical. In particular, efforts should work to improve infiltration and overland flow of roof runoff and diverting overland flows from pervious areas to existing wetlands and permeable soils. Where possible, stormwater from smaller storms (less than 1.25 inches of rainfall) and the first flush of runoff during larger storms discharging from parking lots, roads and other paved areas should be diverted to best management practices that can filter pollutants as well as reduce peak flows and volumes. Where possible, recommendations and BMPs should be integrated into the Holmdel Township Municipal Stormwater Management Plan.

2. Swimming River Reservoir Protection

While phosphorus within Ramanessin Brook is rendered unavailable to plants and algae, phosphorus-rich sediments are delivered through Ramanessin Brook to Swimming River Reservoir. Given the similarities among Ramanessin Brook and the other streams that drain to Swimming River Reservoir, it is very likely that many of these streams are delivering substantial loads of phosphorus-rich sediments to the reservoir (see Figure 22). The names of several of the tributaries to the reservoir (e.g., Yellow Brook, Marl Brook) reinforce the likelihood that Ramanessin Brook is not unique as a source of glauconitic sediment to the reservoir. Within the reservoir under certain circumstances, phosphorus can be released and may stimulate the production of occasional algal blooms in the reservoir. Note that this study did not evaluate the reservoir in any way. Nevertheless, it is very likely that turnover within the reservoir stimulates occasional algal blooms, simply based on the physics of reservoirs and the chemistry of iron and phosphorus. Therefore, in order to mitigate the introduction of phosphorus-rich sediments into Swimming River Reservoir, engineered sediment abatement structures should be considered for the outlets of Ramanessin Brook and other similar reservoir inlet tributaries. As a first step, the glauconitic erosion potential analysis performed for this study could be applied to all the inlet streams in order to prioritize watersheds for engineered sediment abatement structures near the outlet.

Figure 22. Swimming River Reservoir Watershed



3. Navesink / Swimming River Regional Stormwater Management Planning

This study provided a forum for communication among involved communities and entities within the Ramanessin Brook and the larger Navesink/Swimming River watershed as they plan for management of stormwater on a regional scale. The Monmouth County Planning Board has facilitated coordination of a Regional Stormwater Management Committee working towards selection of a Lead Planning Agency. The methodology and the information provided in this study for the Ramanessin Brook watershed provides a template for characterization and understanding of local watershed issues in the regional context. The information that has been collected, modeled and analyzed will be integral to the creation of a comprehensive Regional Stormwater Management Plan and can be used as a benchmark for determining what efforts need to be completed throughout the rest of the watershed to characterize and understand issues and begin developing regional goals. The data and work has been prepared and presented for the RSWMP Committee to assist them in developing a suitable work plan for development of a Regional Stormwater Management Plan. As many of the issues in the Ramanessin Brook watershed are likely to be the same or similar in many of the other impaired waterways of the Navesink/Swimming River watershed, the work completed under this project provides a methodology an baseline evaluation for comparison as the RSWMP Committee plans for improved regional stormwater management.

VII. References

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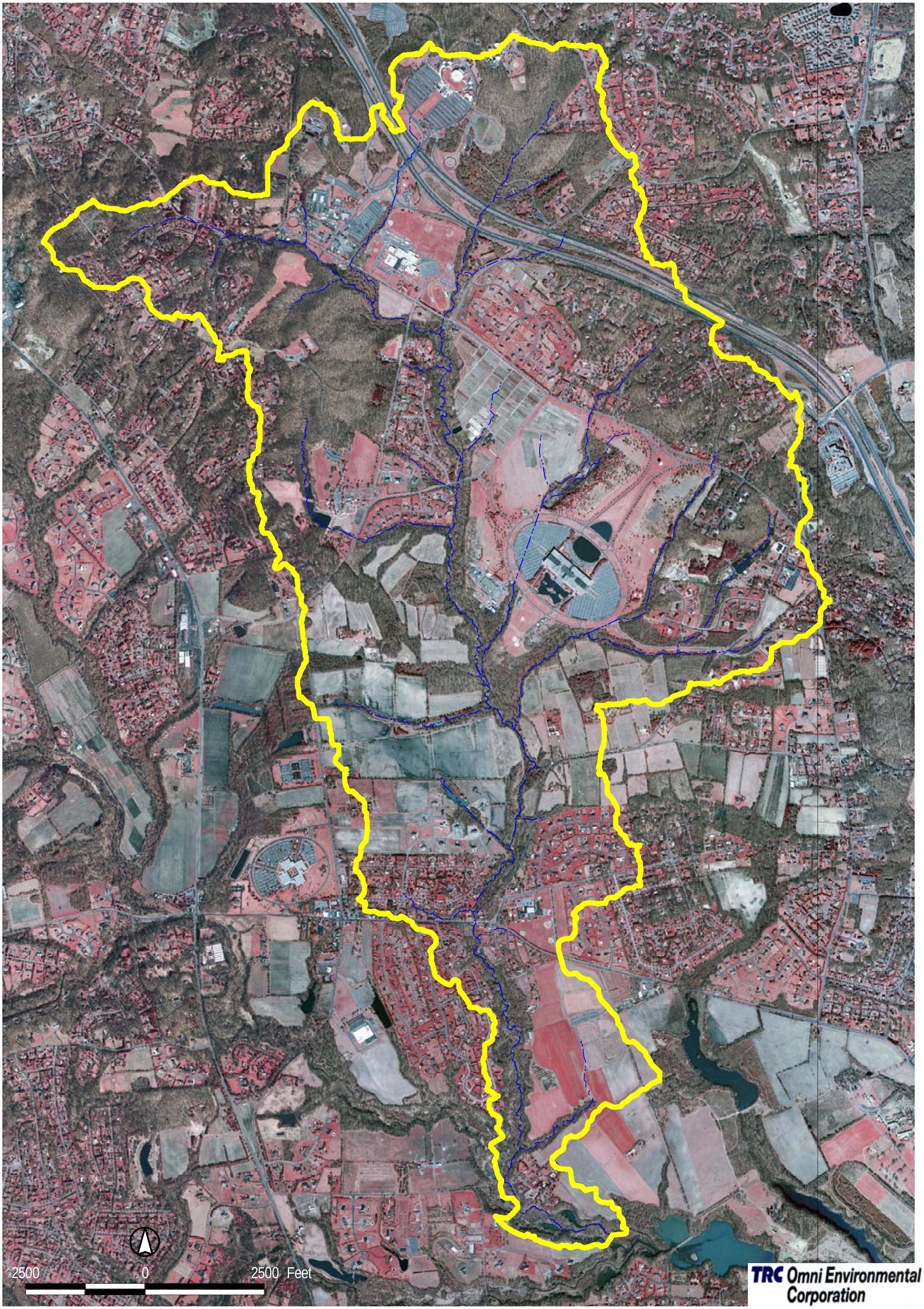
APPENDIX A: Characterization and Assessment Maps

Map 1	Aerial Photo of Ramanessin Brook Watershed
Map 2	Digital Terrain Model (DTM)
Map 3	Land Use Characterization
Map 4	SSURGO Soils
Map 5	Wetlands
Map 6	Ground Water Recharge
Map 7	Impaired Stream Segments

Map 1. Aerial Photo



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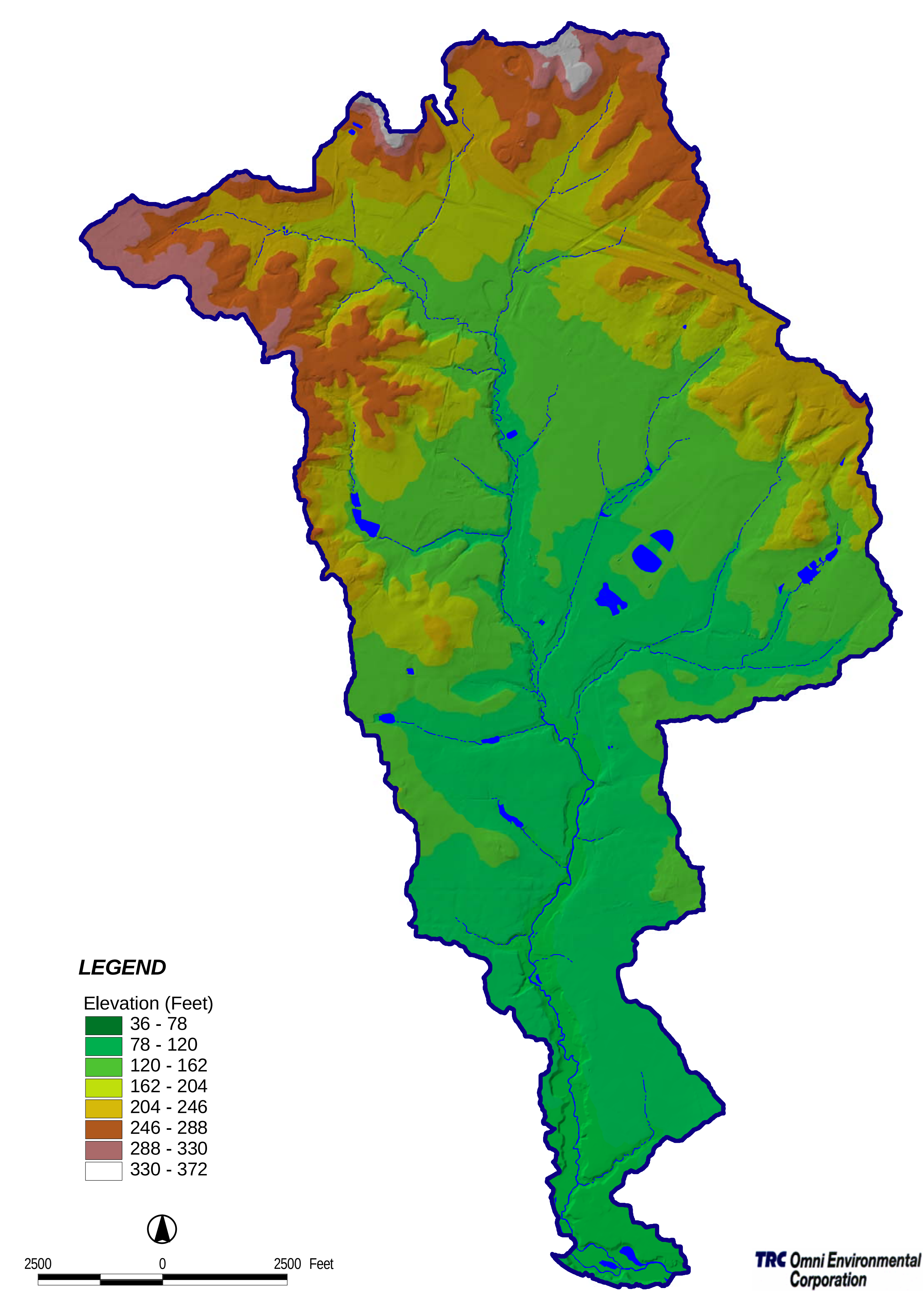
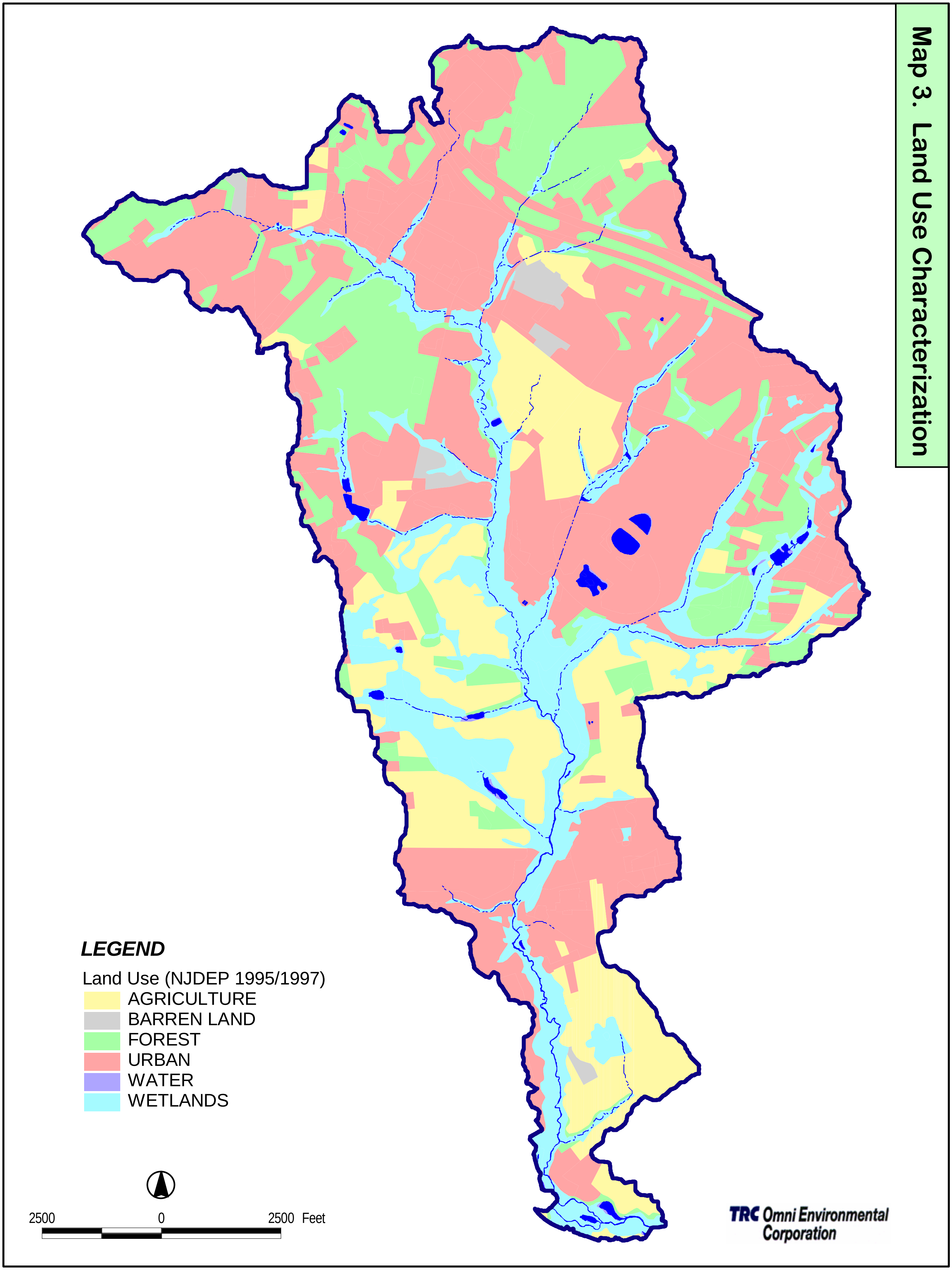
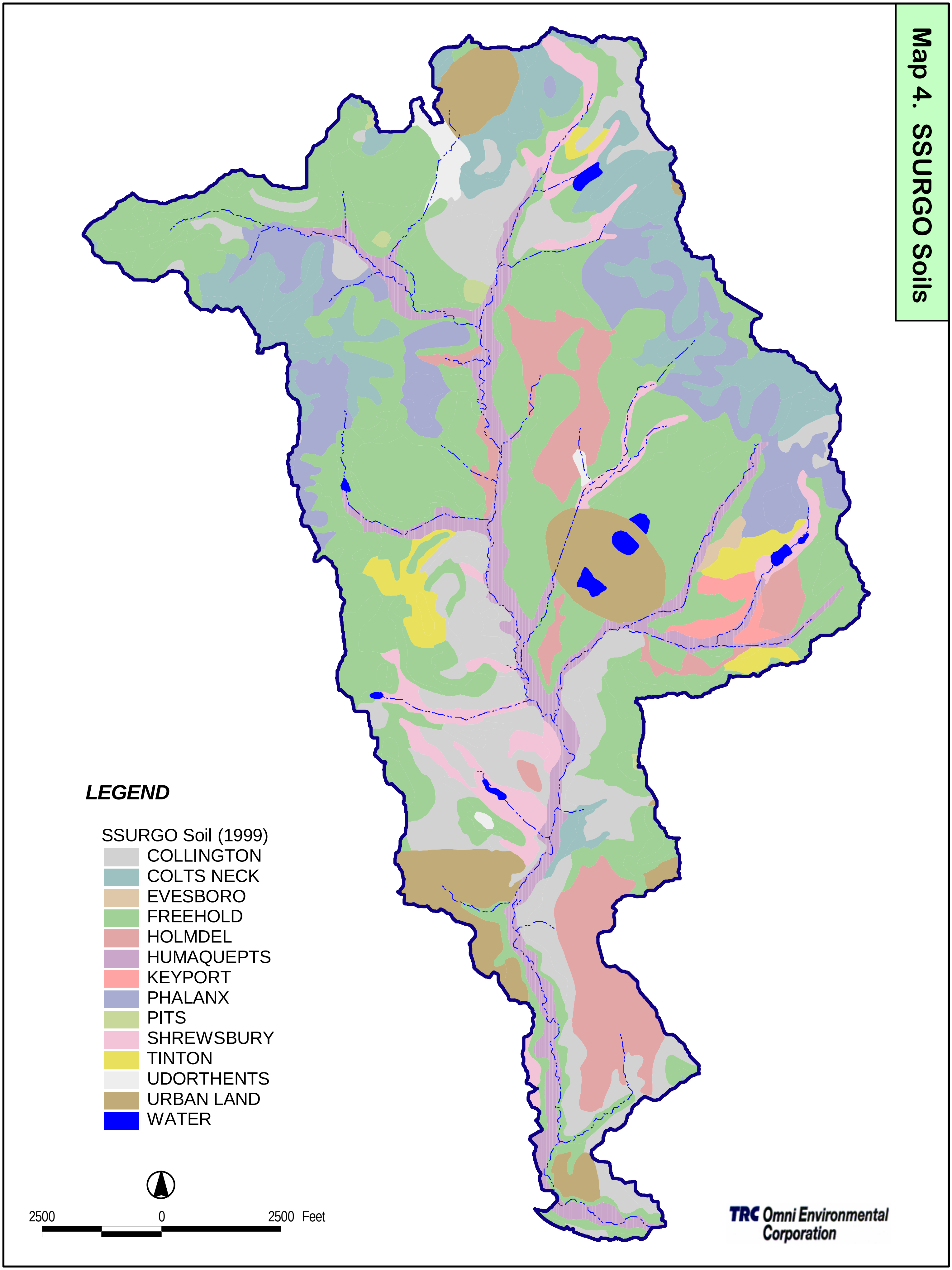
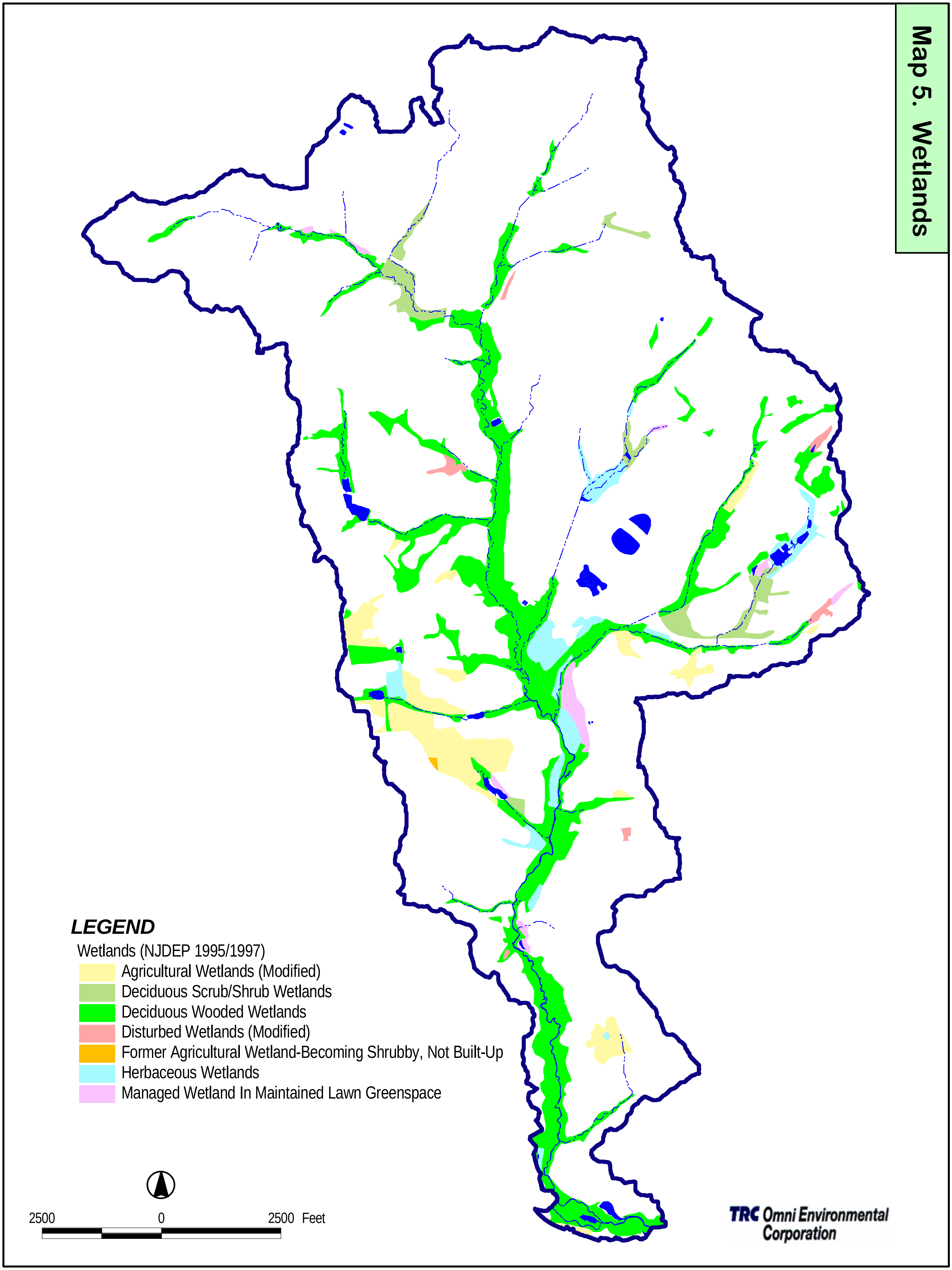
Map 2. Digital Terrain Model (DTM)

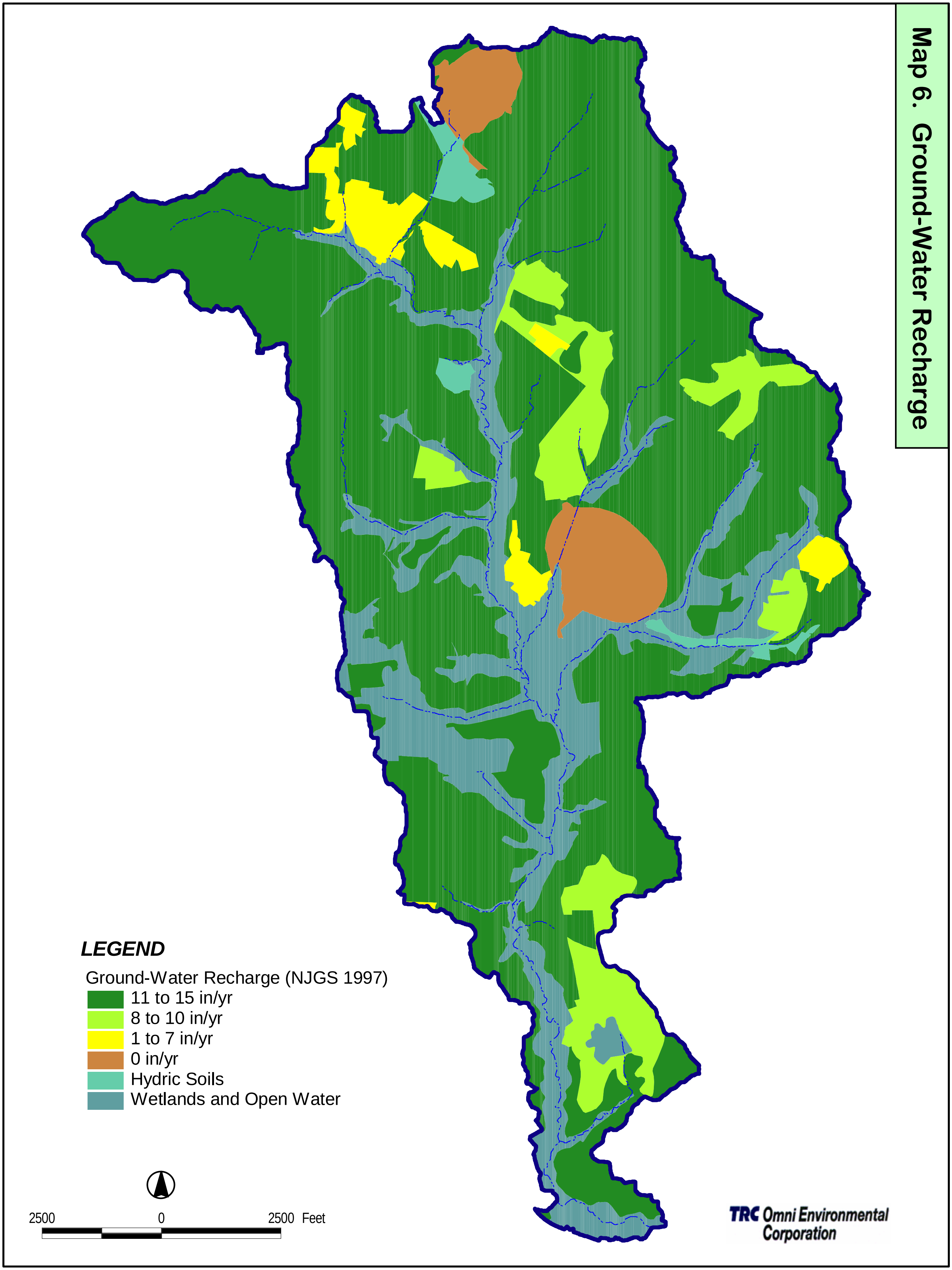


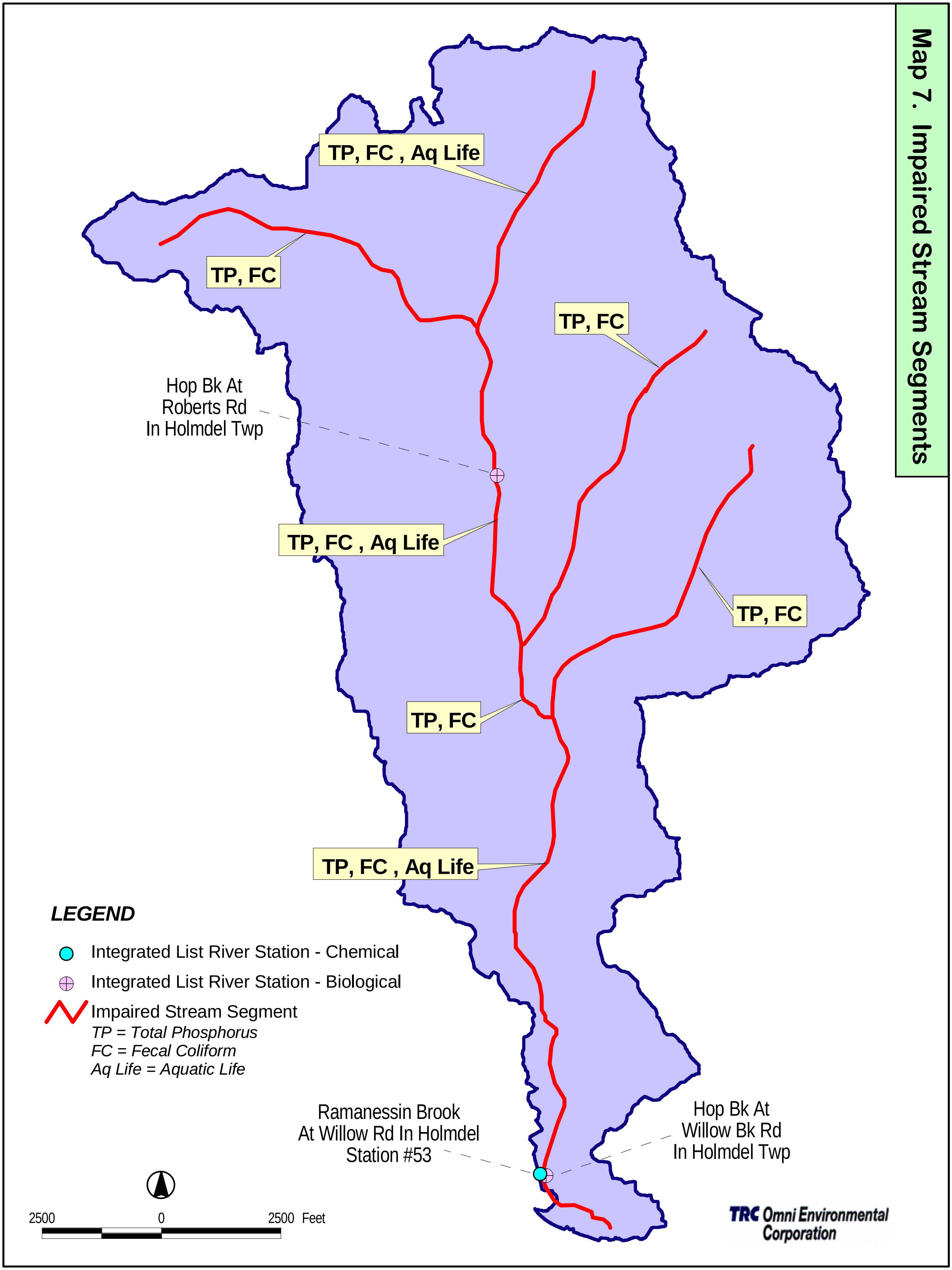


Map 3. Land Use Characterization
LEGEND
Land Use (NJDEP 1995/1997)
AGRICULTURE
BARREN LAND
FOREST
URBAN
WATER
WETLANDS
2500
0
2500 Feet
TRC Omni Environmental Corporation


Map 4. SSURGO Soils
LEGEND
SSURGO Soil (1999)
COLLINGTON
COLTS NECK
EVESBORO
FREEHOLD
HOLMDEL
HUMAQUEPTS
KEYPORT
PHALANX
PITS
SHREWSBURY
TINTON
UDORTHENTS
URBAN LAND
WATER
2500
0
2500 Feet
TRC Omni Environmental Corporation


Map 5. Wetlands
LEGEND
Wetlands (NJDEP 1995/1997)
Agricultural Wetlands (Modified)
Deciduous Scrub/Shrub Wetlands
Deciduous Wooded Wetlands
Disturbed Wetlands (Modified)
Former Agricultural Wetland-Becoming Shrubby, Not Built-Up
Herbaceous Wetlands
Managed Wetland In Maintained Lawn Greenspace
2500 0 2500 Feet
TRC Omni Environmental Corporation


Map 6. Ground-Water Recharge
LEGEND
Ground-Water Recharge (NJGS 1997)
11 to 15 in/yr
8 to 10 in/yr
1 to 7 in/yr
0 in/yr
Hydric Soils
Wetlands and Open Water
2500
0
2500 Feet
TRC Omni Environmental Corporation



Map 7. Impaired Stream Segments
TP, FC , Aq Life
TP, FC
TP, FC
Hop Bk At
Roberts Rd
In Holmdel Twp
TP, FC , Aq Life
TP, FC
TP, FC
TP, FC , Aq Life
LEGEND
Integrated List River Station - Chemical
Integrated List River Station - Biological
Impaired Stream Segment
TP = Total Phosphorus
FC = Fecal Coliform
Aq Life = Aquatic Life
Ramanessin Brook
At Willow Rd In Holmdel
Station #53
Hop Bk At
Willow Bk Rd
In Holmdel Twp
2500
0
2500 Feet
TRC Omni Environmental Corporation

APPENDIX B: Water Quality Monitoring Data

Appendix B: 6000 Ramanessin Brook Data Table

Sample Location	Date-Time	Flow	Dissolved Oxygen	pH	Temperature	Dissolved Reactive Phosphorus	Total Phosphorus	Iron	Total Suspended Solids	Turbidity	Fecal Coliforms	Fecal Streptococci	FC/FS Ratio
		cfs	mg/l	s.u.	ºC	mg/l	mg/l	mg/l	mg/l	NTU	colonies/100 ml	colonies/100 ml	
Base	7/22/04 14:10		8.07	6.70	21.40	< 0.01	0.04	1.59	24	9.3			
	7/30/04 11:50		8.42	7.66		< 0.01	0.04	0.90	3	3.3	90		
	8/3/04 13:10		8.31	6.54	21.20	< 0.01	0.03	1.07	5	3.7	110		
	8/19/04 12:55		8.29	6.84	20.70	0.02	0.06	2.85	25	4.9	92		
	9/1/04 14:30		8.57	6.67	21.60	< 0.01	< 0.02	0.98	3	3.6	1800		
	9/29/04 13:30		8.69	5.82	16.10	< 0.01	0.03	1.12	7	9.1	600		
	10/19/04 13:40					0.01	0.04	1.20	5	4.7	310		
RB1	7/22/04 13:10	0.05	7.69	6.46	20.90	< 0.01	0.03	0.33	2	1.9	730		
	7/30/04 12:40	0.12	7.84	6.80	20.00	< 0.01	0.03	0.26	1	1.5	1100		
	8/3/04 13:55	0.10	7.75	6.66	21.00	0.01	0.03	0.30	3	2.1	830		
	8/19/04 11:40	0.10	7.84	6.83	20.40	< 0.01	< 0.02	0.47	4	1.9	230		
	9/1/04 13:30	0.04	7.81	6.82	23.20	0.02	0.10	0.85	8	3.8	3200		
	9/29/04 12:45	0.37	8.5	7.12	17.80	0.03	0.08	1.39	5	14.2	3300		
	10/15/04 12:44	0.10	8.5	6.95	14.80	< 0.06	0.04	0.63	3	3.6	140		
	10/19/04 12:25	1.68	9.77	7.50	12.40	0.05	0.09	1.03	6	14.6	6600		
	11/17/04 13:30	0.19	10.5	7.14	10.40	< 0.01	0.04	0.95	< 1	1.3	44		
	11/23/04 10:21	0.18	10.1	6.59	10.70	< 0.01	0.03	0.67	< 1	1.0	18		
	12/6/04 11:50	0.39	11.1	6.67	6.80	< 0.01	0.05	0.80	1	2.7	12		
	12/22/04 14:10	0.33	11.6	6.69	6.00	< 0.01	0.02	1.00	1	4.2	8		
	1/6/05 13:45	8.81	11.8	7.29	6.00	0.02	0.06	1.40	3	12.0	110		
	1/13/05 11:45	0.61	11.4	7.15	8.90	< 0.01	0.02	0.63	1	1.3	< 4		
	2/8/05 14:40	0.89	11.9	6.85	6.60	< 0.01	0.03	1.07	7	7.1	4		
	2/15/05 11:15	1.65	11.6	6.71	6.60	0.01	0.04	1.17	4	10.0	8		
	3/23/05 13:30	2.60	11.9	6.80	5.10	< 0.01	0.23	7.01	77	78.0	550	180	3.06
	3/30/05 11:15	1.25	11.3	6.39	9.60	< 0.01	0.02	0.67	4	3.1	28	20	1.40
	4/6/05 12:30	0.85	10.8	6.76	14.00	< 0.01	0.03	0.61	3	1.8	5	< 5	
	4/13/05 15:05	0.70	9.91	7.06	13.60	< 0.01	0.02	0.58	< 1	1.4	3	2	1.50
	5/3/05 13:35	1.04	10.2	6.33	12.00	< 0.01	0.02	0.49	1	1.5	24	44	0.55
	5/20/05 12:45	6.99	10	6.23	11.90	0.11	0.24	2.57	27	29.0	4300	7500	0.57
	6/2/05 11:20	0.50	9.42	5.83	13.70	0.02	0.02	0.47	4	1.7	230	200	1.15
	6/29/05 11:50	0.06	7.98	6.02	20.20	< 0.01	0.04	0.46	2	2.6	880	530	1.66
RB2	7/22/04 13:30	0.06	7.63	6.81	21.90	0.02	0.05	0.43	4	1.9	900		
	7/30/04 13:00	0.16	7.65	6.90	21.20	0.02	0.06	0.32	2	1.7	640		
	8/3/04 14:15	0.16	7.57	6.82	23.00	0.02	0.04	0.39	2	1.6	910		
	8/19/04 12:30	0.13	7.58	6.91	21.30	0.01	0.03	0.45	2	1.3	660		
	9/1/04 14:00	0.16	7.9	7.01	20.80	0.03	0.09	0.89	22	7.3	40		
	9/29/04 13:15	0.59	8.19	5.55	18.30	0.58	0.74	2.75	21	24.2	46000		
	10/15/04 14:55	0.11	8.15	7.43	16.00	< 0.06	0.09	0.85	3	4.8	1100		
	10/19/04 13:15	2.99	9.71	7.19	12.20	0.05	0.10	1.18	8	17.8	4900		
	11/17/04 14:00	0.82	11	6.93	7.70	0.02	0.05	0.99	1	1.3	120		
	11/23/04 10:35	0.28	10.5	6.52	9.40	0.01	0.03	0.87	< 1	2.1	100		
	12/6/04 12:05	0.32	11.7	6.70	5.50	0.01	0.05	0.95	1	2.7	88		
	12/22/04 14:40	0.59	13	6.98	6.50	0.01	0.07	2.07	8	14.0	180		
	1/6/05 14:05	2.96	11.6	7.08	5.70	0.05	0.12	2.30	8	17.0	820		
	1/13/05 12:05	1.00	11.4	6.94	8.50	0.02	0.05	1.00	2	3.2	460		
	2/8/05 15:10	0.97	11.6	6.97	6.10	< 0.01	0.05	2.15	12	9.2	32		
	2/15/05 11:40	2.51	11.5	6.69	6.90	0.05	0.14	2.09	9	18.0	590		
	3/23/05 12:30	10.61	11.6	7.37	4.50	< 0.01	0.94	44.10	440	390	2400	400	6.00
	3/30/05 11:40	1.50	10.5	6.34	10.90	0.09	0.17	1.45	5	5.2	1100	550	2.00
	4/6/05 12:50	1.44	9.73	6.73	14.20	0.06	0.12	1.54	6	3.1	80	120	0.67
	4/13/05 15:25	1.01	9.54	6.89	13.70	0.03	0.07	1.08	1	2.9	18	7	2.57
	5/3/05 14:25	0.89	9.98	6.44	12.40	0.01	0.04	0.74	< 1	2.4	150	100	1.50
	5/20/05 13:15	8.75	9.93	6.32	12.20	0.08	0.28	2.61	43	53.0	18000	9400	1.91
	6/2/05 11:55	0.41	9.79	6.18	13.30	0.01	0.08	1.13	6	4.4	210	250	0.84
	6/29/05 12:20	0.04	7.59	7.23	19.90	0.03	0.08	0.75	6	2.6	670	480	1.40

Appendix B: 6000 Ramanessin Brook Data Table

Sample Location	Date-Time	Flow	Dissolved Oxygen	pH	Temperature	Dissolved Reactive Phosphorus	Total Phosphorus	Iron	Total Suspended Solids	Turbidity	Fecal Coliforms	Fecal Streptococci	FC/FS Ratio
		cfs	mg/l	s.u.	ºC	mg/l	mg/l	mg/l	mg/l	NTU	colonies/100 ml	colonies/100 ml	
RB3	7/22/04 12:40	0.62	7.74	6.89	20.40	0.02	0.12	2.27	6	13.2	130		
	7/30/04 12:05	0.85	7.79	6.92	19.50	0.03	0.11	1.19	2	6.8	240		
	8/3/04 13:25	0.64	7.73	6.51	21.20	0.02	0.07	1.37	5	5.4	1000		
	8/19/04 11:10	0.59	7.8	6.95	19.00	0.01	0.06	1.72	4	4.7	1100		
	9/1/04 13:05	0.49	7.66	7.14	19.20	0.04	0.13	2.22	8	10.5	140		
	9/29/04 12:15	1.90	7.72	6.93	18.60	0.10	0.28	3.00	18	25.0	48000		
	10/15/04 11:55	0.72	8.18	7.08	13.80	< 0.06	0.07	1.10	4	7.4	1000		
	10/19/04 12:05	6.28	9.3	7.60	12.00	0.04	0.10	1.72	12	18.9	7900		
	11/17/04 12:55	0.84	10.4	7.15	8.60	#DIV/0!	0.08	2.09	1	2.4	32		
	11/23/04 9:58	1.00	9.77	6.77	10.50	< 0.01	0.06	1.93	2	3.7	180		
	12/6/04 11:35	1.12	11	6.74	6.60	< 0.01	0.08	1.73	3	6.1	32		
	12/22/04 13:50	1.28	11.8	7.26	5.20	< 0.01	0.05	1.82	1	5.9	44		
	1/6/05 13:20	10.62	11.5	7.41	5.60	0.04	0.11	2.50	8	18.0	2400		
	1/13/05 11:26	2.18	11.3	7.27	8.70	0.02	0.06	1.34	1	3.7	48		
	2/8/05 14:25	1.22	11.3	7.13	3.20	< 0.01	0.06	2.05	6	8.4	44		
	2/15/05 11:00	4.96	11.3	6.75	6.30	0.03	0.11	2.13	12	16.0	280		
	3/23/05 13:05	16.58	11.4	7.08	5.20	< 0.01	0.53	37.60	440	330	1400	370	3.78
	3/30/05 11:00	3.93	10.9	6.27	9.00	0.04	0.08	1.27	4	4.8	290	150	1.93
	4/6/05 12:10	3.18	10.6	7.07	13.30	0.03	0.06	1.21	6	2.4	15	5	3.00
	4/13/05 14:45	2.41	10.1	7.02	13.60	0.02	0.08	1.19	1	3.2	22	6	3.67
	5/3/05 12:45	2.43	10	7.16	14.30	0.02	0.05	1.17	1	3.1	88	42	2.10
	5/20/05 12:15	29.42	9.41	6.26	12.20	0.09	0.50	4.88	82	79.0	11500	12200	0.94
	6/2/05 11:00	1.30	9.39	6.18	13.50	< 0.01	0.08	1.89	7	6.7	120	96	1.25
	6/29/05 11:30	0.32	7.75	6.65	21.10	0.03	0.10	1.80	6	6.6	180	470	0.38
RB4	7/22/04 12:15	3.17	8.54	7.00	20.60	0.01	0.08	0.63	1	4.0	480		
	7/30/04 11:15	4.10	8.21	7.08	20.90	0.04	0.10	0.74	3	4.9	280		
	8/3/04 12:35	5.29	8.19	7.29	23.60	0.04	0.10	0.90	7	5.2	890		
	8/19/04 10:15	3.04	8.3	7.47	19.00	0.02	0.04	0.62	4	2.9	1100		
	9/1/04 12:26	3.29	8.32	7.57	19.40	0.04	0.10	1.09	5	5.1	220		
	9/29/04 11:35	6.87	8.09	7.17	18.40	0.05	0.29	6.50	43	51.4	50000		
	10/15/04 14:10	2.67	8.94	7.42	14.30	< 0.06	0.05	0.47	1	3.9	720		
	10/19/04 11:30	19.24	9.61	7.70	13.10	0.03	0.22	4.17	33	20.0	8000		
	11/17/04 12:15	3.99	11.3	7.20	8.10	0.01	0.09	1.10	1	3.7	96		
	11/23/04 9:42	4.13	10.9	7.38	10.80	< 0.01	0.05	0.95	2	4.6	110		
	12/6/04 11:20	4.42	11.5	6.60	6.30	< 0.01	0.05	1.02	3	4.6	72		
	12/22/04 13:25	5.07	12.3	7.52	5.20	< 0.01	0.05	1.25	3	6.9	48		
	1/6/05 12:52	14.05	12.1	7.87	5.50	0.04	0.15	3.56	17	26.0	2300		
	1/13/05 11:45	7.31	11.5	7.67	8.10	0.02	0.05	0.99	3	4.3	60		
	2/8/05 13:45	7.32	12.2	7.22	6.20	< 0.01	0.04	1.03	3	5.2	8		
	2/15/05 10:25	26.85	11.8	6.81	5.70	0.03	0.17	3.44	22	31.0	960		
	3/23/05 14:18	28.13	11.8	6.97	5.50	0.02	0.43	10.10	73	67.0	890	580	1.53
	3/30/05 10:25	15.71	11.7	7.25	9.10	0.02	0.11	2.18	15	19.0	270	200	1.35
	4/6/05 11:40	11.89	11.4	7.41	12.60	0.02	0.08	1.22	7	8.6	40	20	2.00
	4/13/05 13:40	10.98	10.5	6.81	13.80	0.02	0.08	1.04	3	4.0	22	8	2.75
	5/3/05 12:00	9.25	10.5	7.30	13.10	0.02	0.13	0.94	3	3.9	90	32	2.81
	5/20/05 11:25	49.15	9.51	6.14	11.80	0.06	1.11	15.40	180	140	14400	12000	1.20
	6/2/05 10:35	4.68	9.75	6.69	13.30	0.02	0.05	1.11	5	3.9	140	64	2.19
	6/29/05 10:40	3.77	8.28	6.62	21.30	0.03	0.11	1.28	8	7.3	1000	500	2.00

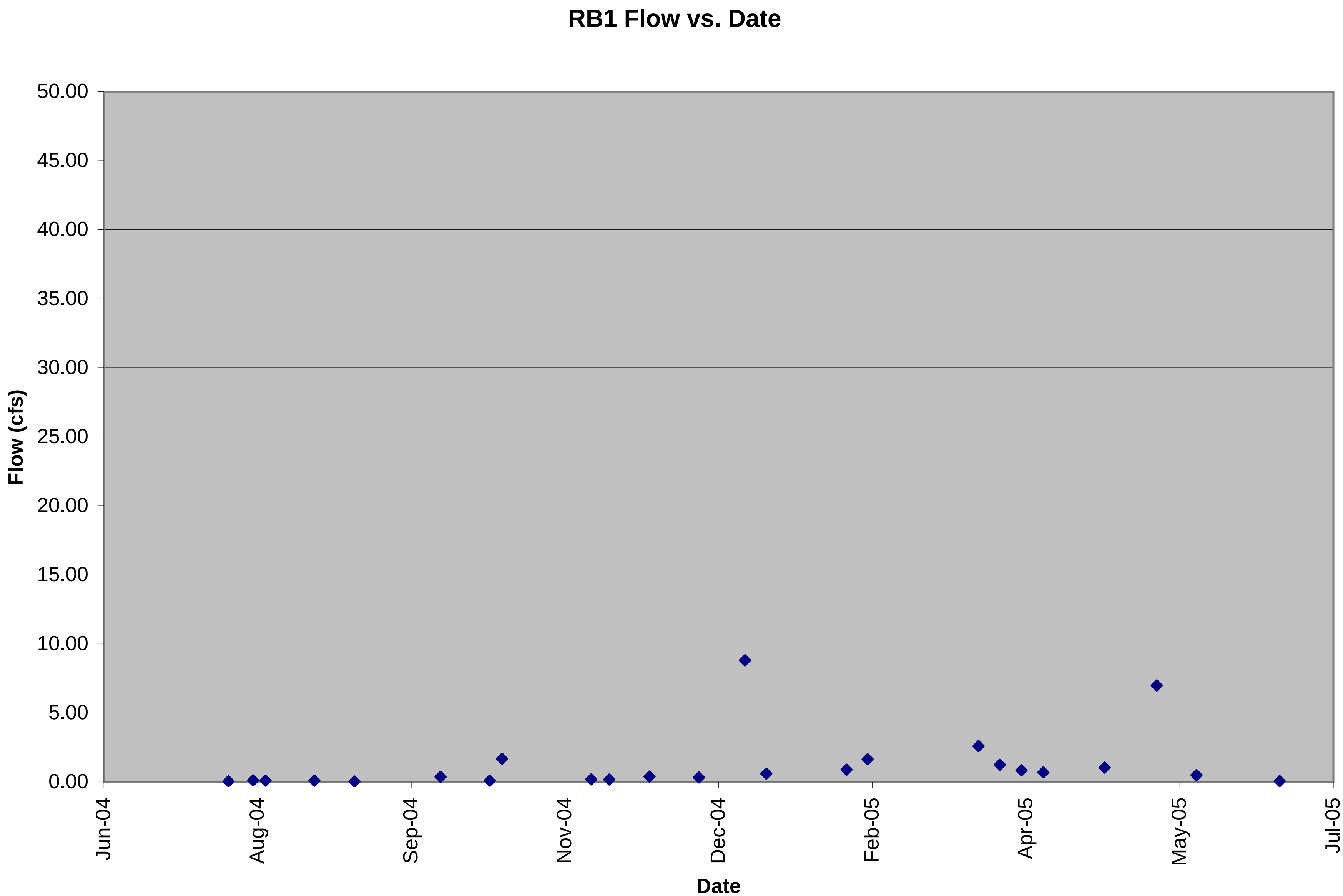
Appendix B: 6000 Ramanessin Brook Data Table

Sample Location	Date-Time	Flow	Dissolved Oxygen	pH	Temperature	Dissolved Reactive Phosphorus	Total Phosphorus	Iron	Total Suspended Solids	Turbidity	Fecal Coliforms	Fecal Streptococci	FC/FS Ratio
		cfs	mg/l	s.u.	ºC	mg/l	mg/l	mg/l	mg/l	NTU	colonies/100 ml	colonies/100 ml	
RB5	7/22/04 11:40	4.53	8.38	6.42	20.70	0.02	0.08	0.67	5	4.6	580		
	7/30/04 10:45	5.37	8.39	7.06	19.70	0.05	0.10	1.05	6	6.7	1000		
	8/3/04 12:05	5.83	8.17	7.25	22.30	0.09	0.10	0.95	9	5.0	440		
	8/19/04 9:15	3.28	8.5	7.55	19.00	0.03	0.07	0.59	4	2.4	600		
	9/1/04 12:10	3.71	8.27	7.34	19.70	0.04	0.16	1.93	13	7.6	240		
	9/29/04 11:05	8.30	6.95	7.56	18.80	0.06	0.33	7.28	43	68.8	28000		
	10/15/04 10:10	3.04	9.11	7.81	13.10	< 0.06	0.05	0.38	< 1	2.8	410		
	10/19/04 14:00		8.99	6.72	11.90	0.04	0.18	3.13	25	31.9	3000		
	11/17/04 11:40	5.43	11.8	7.06	7.30	0.01	0.04	0.86	< 1	3.9	120		
	11/23/04 9:08	5.12	10.5	7.45	10.20	< 0.01	0.04	0.83	3	4.6	200		
	12/6/04 10:45	5.92	11.8	6.35	6.00	< 0.01	0.03	0.85	2	4.1	76		
	12/22/04 13:00	5.30	12.7	7.66	4.70	0.01	0.04	0.92	3	7.7	130		
	1/6/05 12:34	38.88	12	8.11	5.40	0.04	0.22	4.80	27	35.0	3300		
	1/13/05 10:26	11.59	11.8	8.28	7.50	0.02	0.06	1.01	4	4.7	110		
	2/8/05 13:25	7.28	12.3	6.97	5.60	< 0.01	0.07	1.50	15	10.0	36		
	2/15/05 9:45	38.13	11.8	6.66	5.30	0.04	0.27	5.73	34	46.0	1600		
	3/23/05 14:50	20.51	12	7.01	5.50	0.02	0.31	5.77	39	25.0	820	270	3.04
	3/30/05 9:45	13.35	11.7	7.88	7.00	0.02	0.12	2.44	18	22.0	550	250	2.20
	4/6/05 11:00	11.14	11.9	7.99	10.30	0.01	0.09	1.07	7	8.1	75	40	1.88
	4/13/05 13:10	8.66	10.8	6.69	12.30	0.02	0.08	0.89	1	3.9	54	8	6.75
	5/3/05 10:20	8.80	10.8	6.75	10.00	0.02	0.07	0.85	3	3.7	230	110	2.09
	5/20/05 10:45	18.33	9.19	6.29	11.60	0.06	0.55	7.19	56	45.0	11300	6200	1.82
	6/2/05 9:50	4.17	9.64	6.90	13.00	0.03	0.08	1.09	5	3.5	290	180	1.61
	6/29/05 9:10	3.89	8.22	6.88	21.10	0.03	0.15	1.47	9	8.3	340	660	0.52

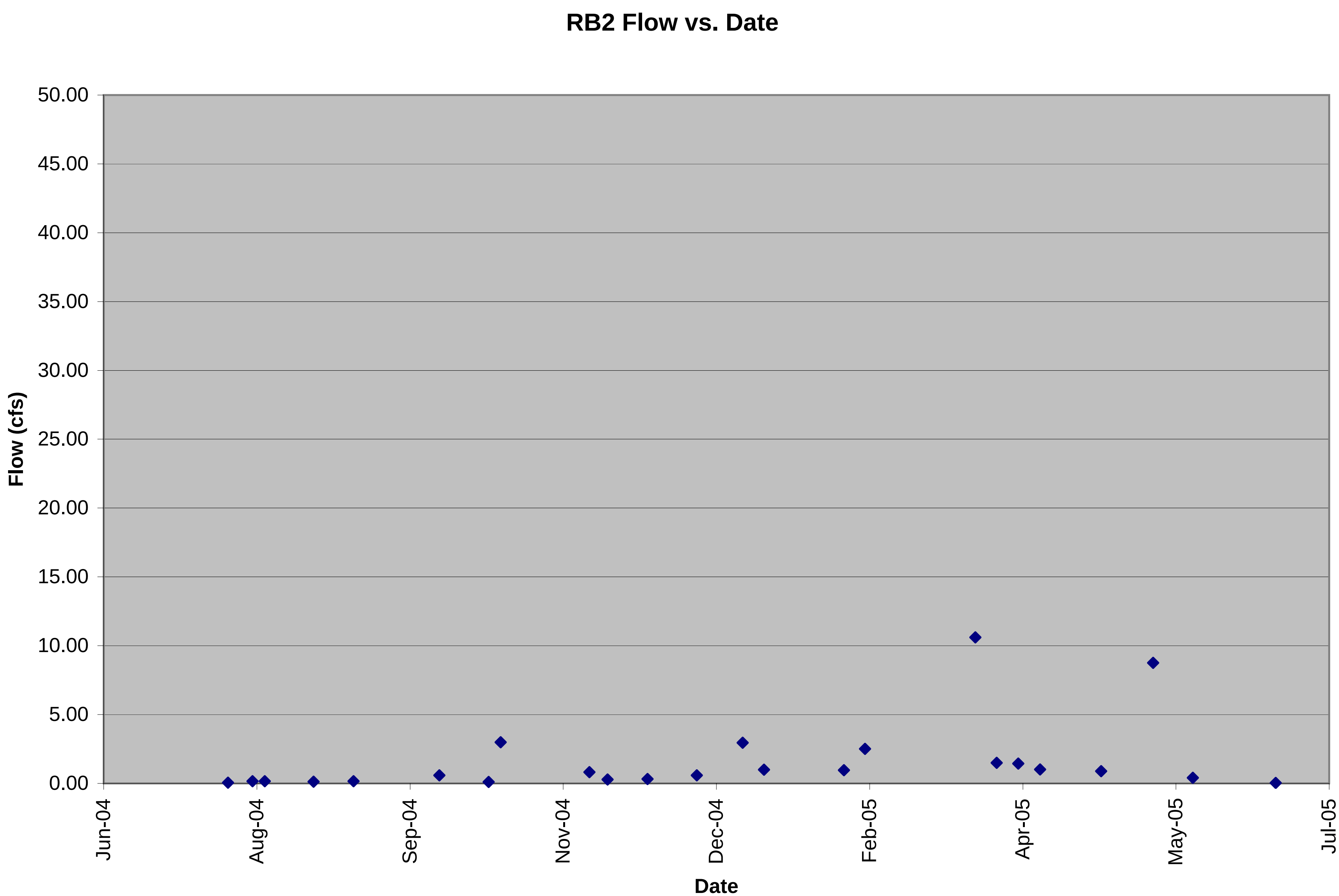
APPENDIX C: Flow Monitoring Graphs

Stream Flow Measurements

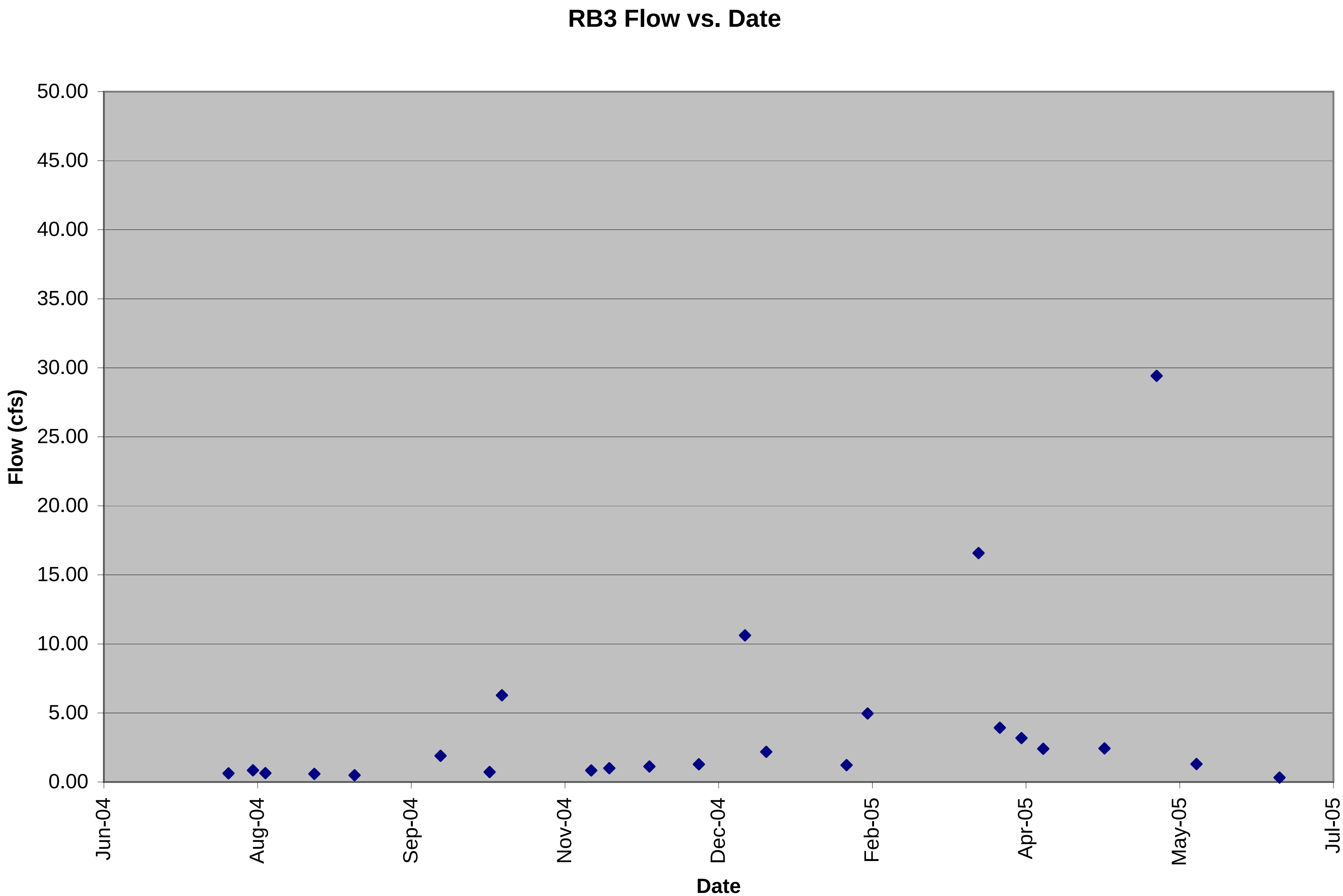
Continuous Depth Measurements (Pressure Transducers)

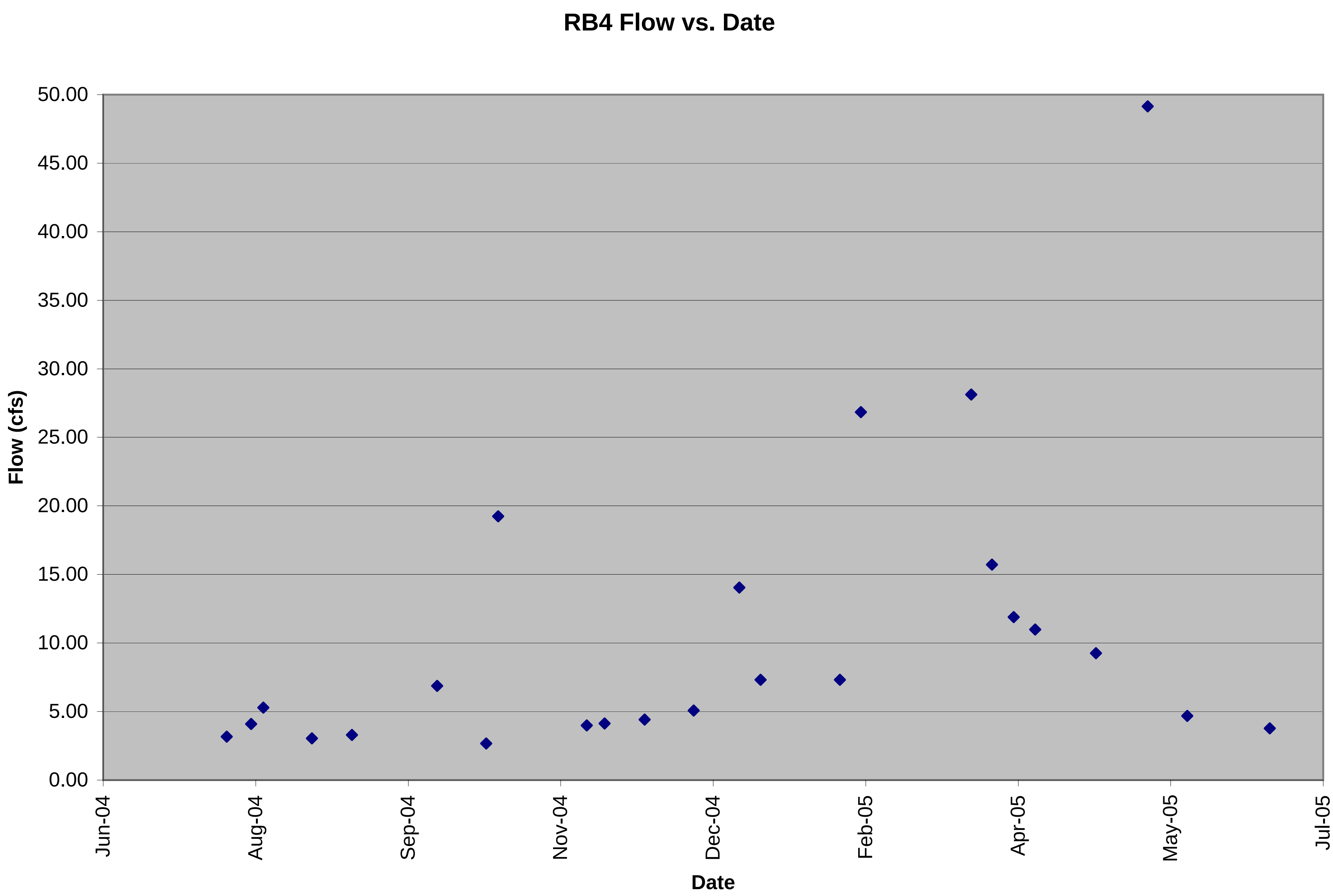


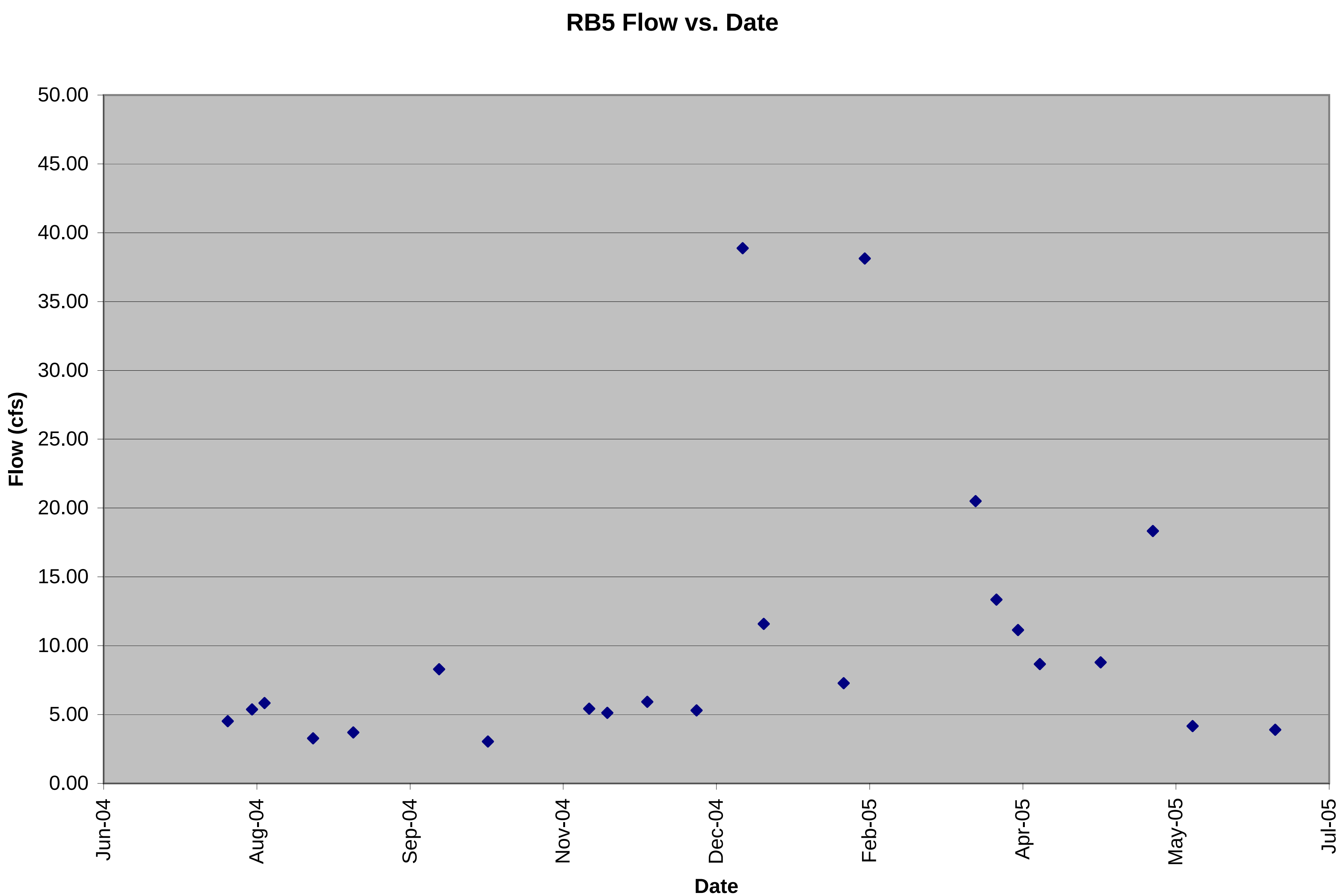
RB1 Flow vs. Date
Flow (cfs)
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Jun-04
Aug-04
Sep-04
Nov-04
Dec-04
Feb-05
Apr-05
May-05
Jul-05
Date

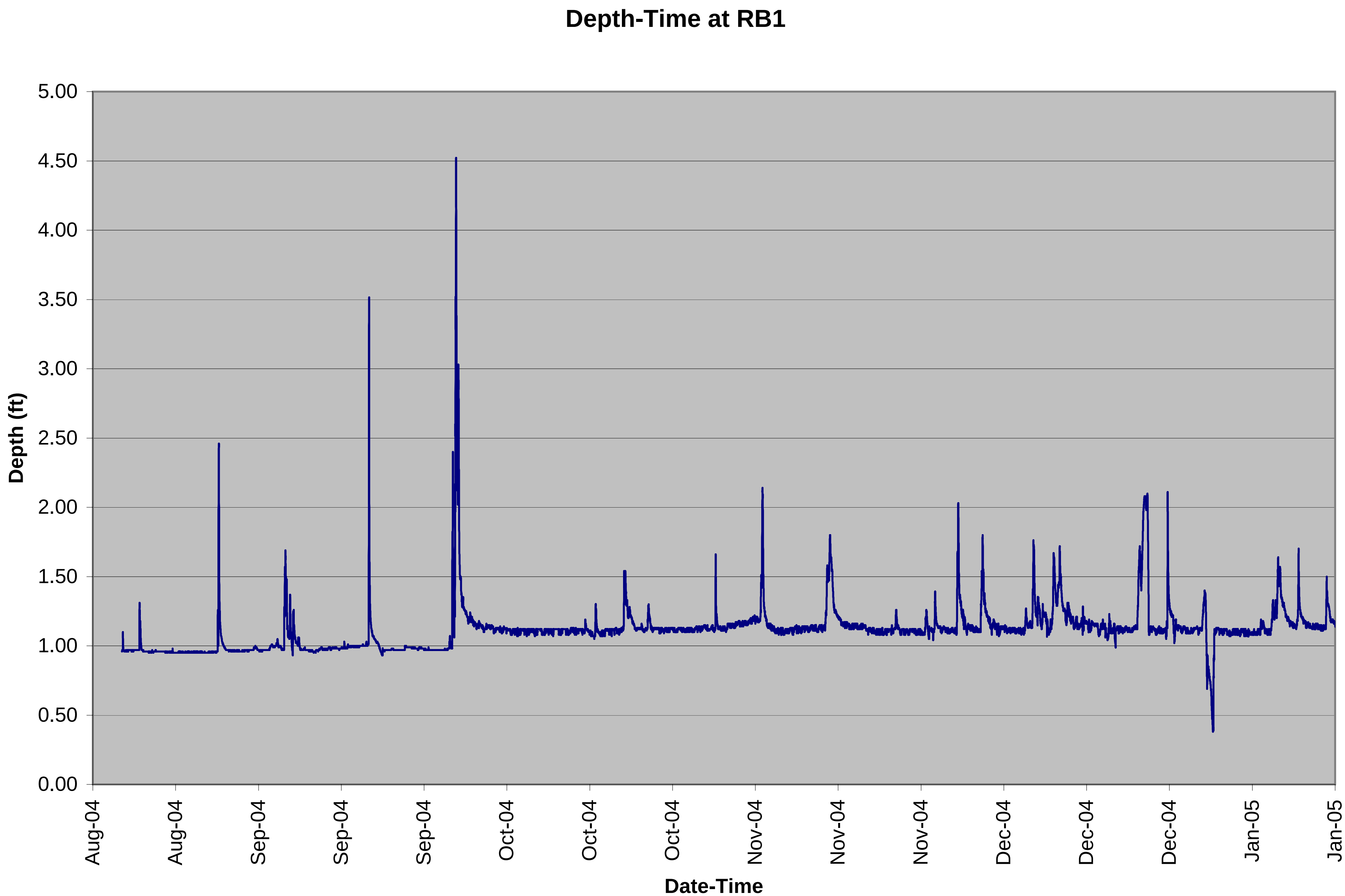


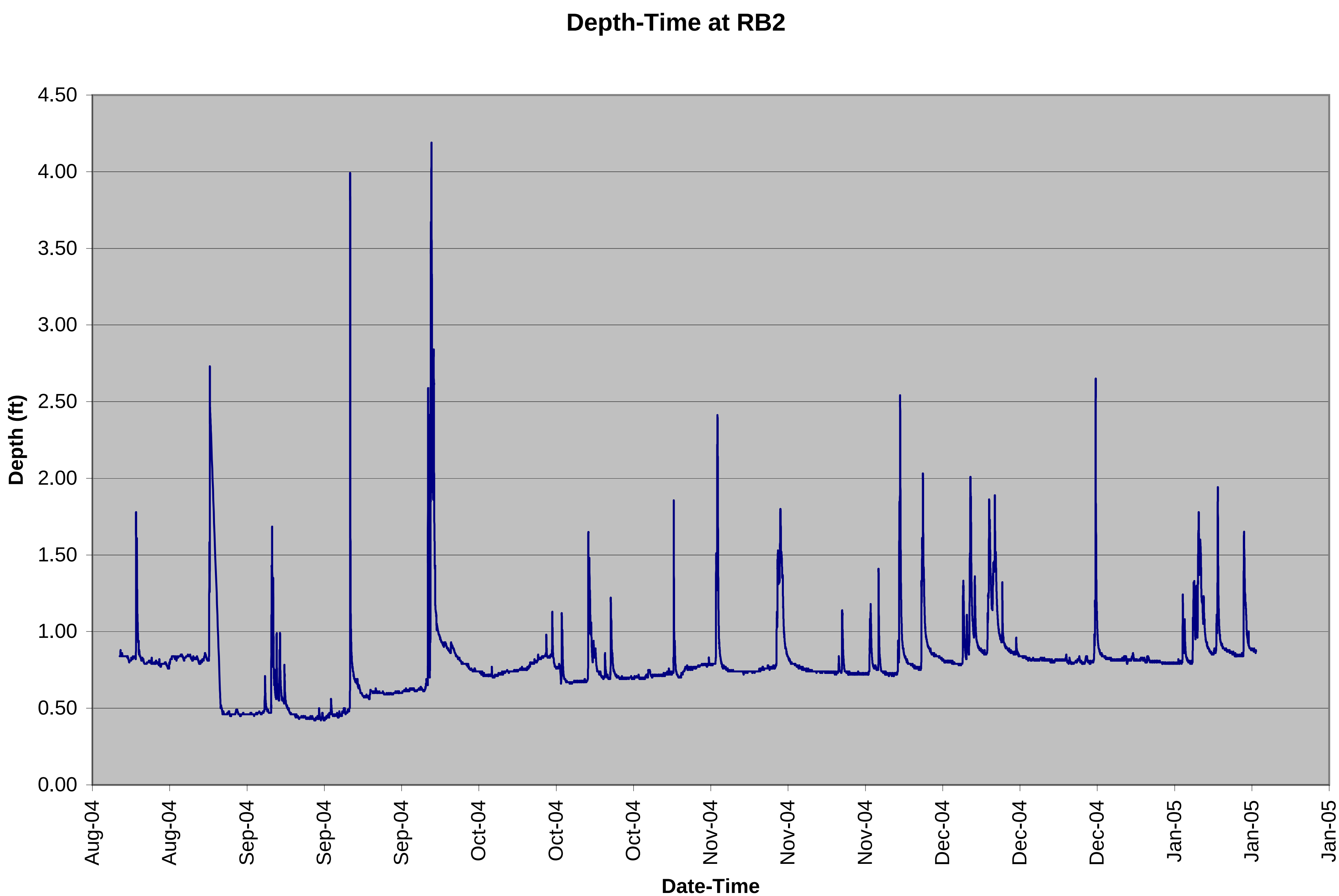
RB2 Flow vs. Date
Flow (cfs)
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Jun-04
Aug-04
Sep-04
Nov-04
Dec-04
Feb-05
Apr-05
May-05
Jul-05
Date


RB3 Flow vs. Date
Flow (cfs)
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Jun-04
Aug-04
Sep-04
Nov-04
Dec-04
Feb-05
Apr-05
May-05
Jul-05
Date

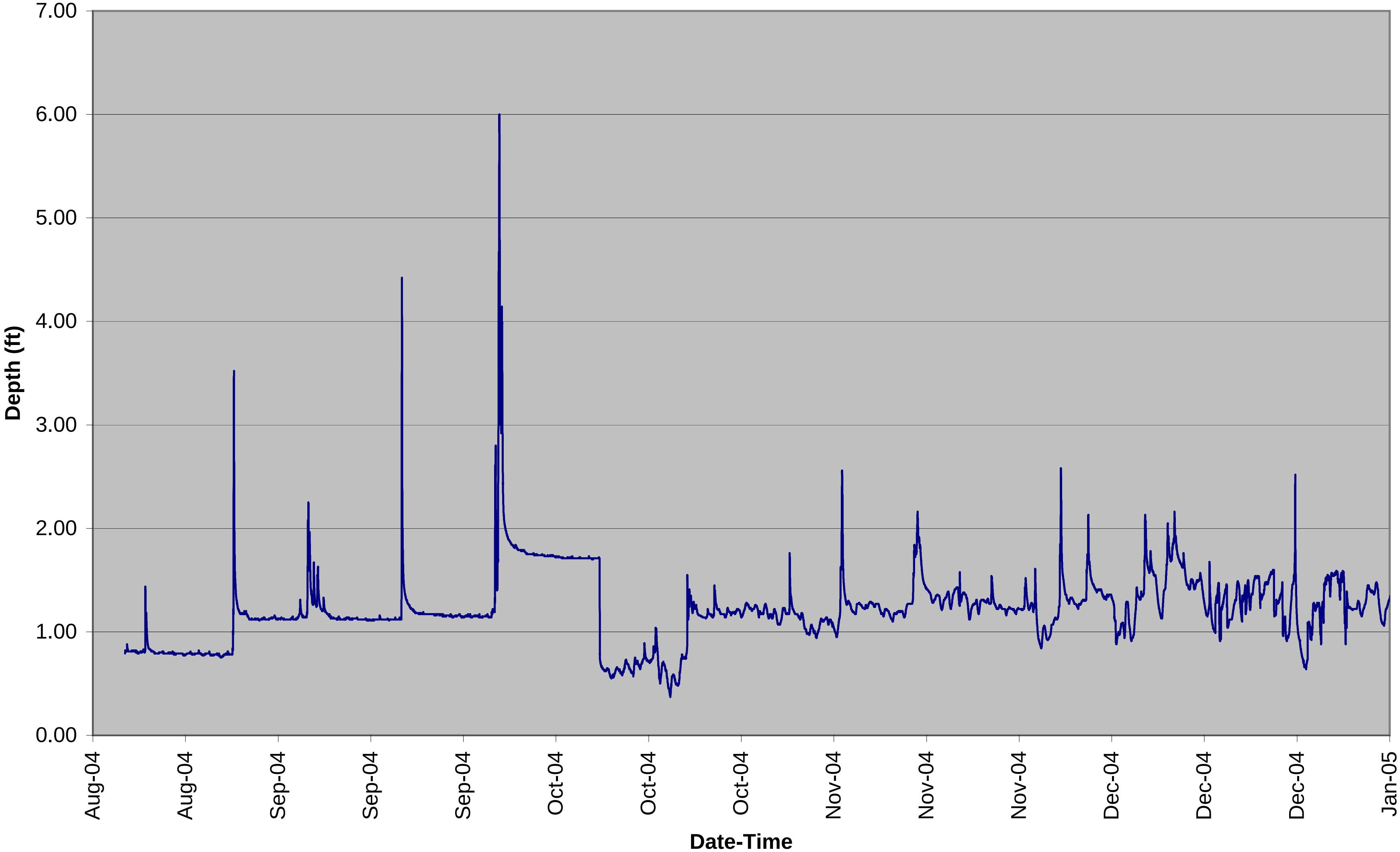

RB4 Flow vs. Date
Flow (cfs)
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Jun-04
Aug-04
Sep-04
Nov-04
Dec-04
Feb-05
Apr-05
May-05
Jul-05
Date

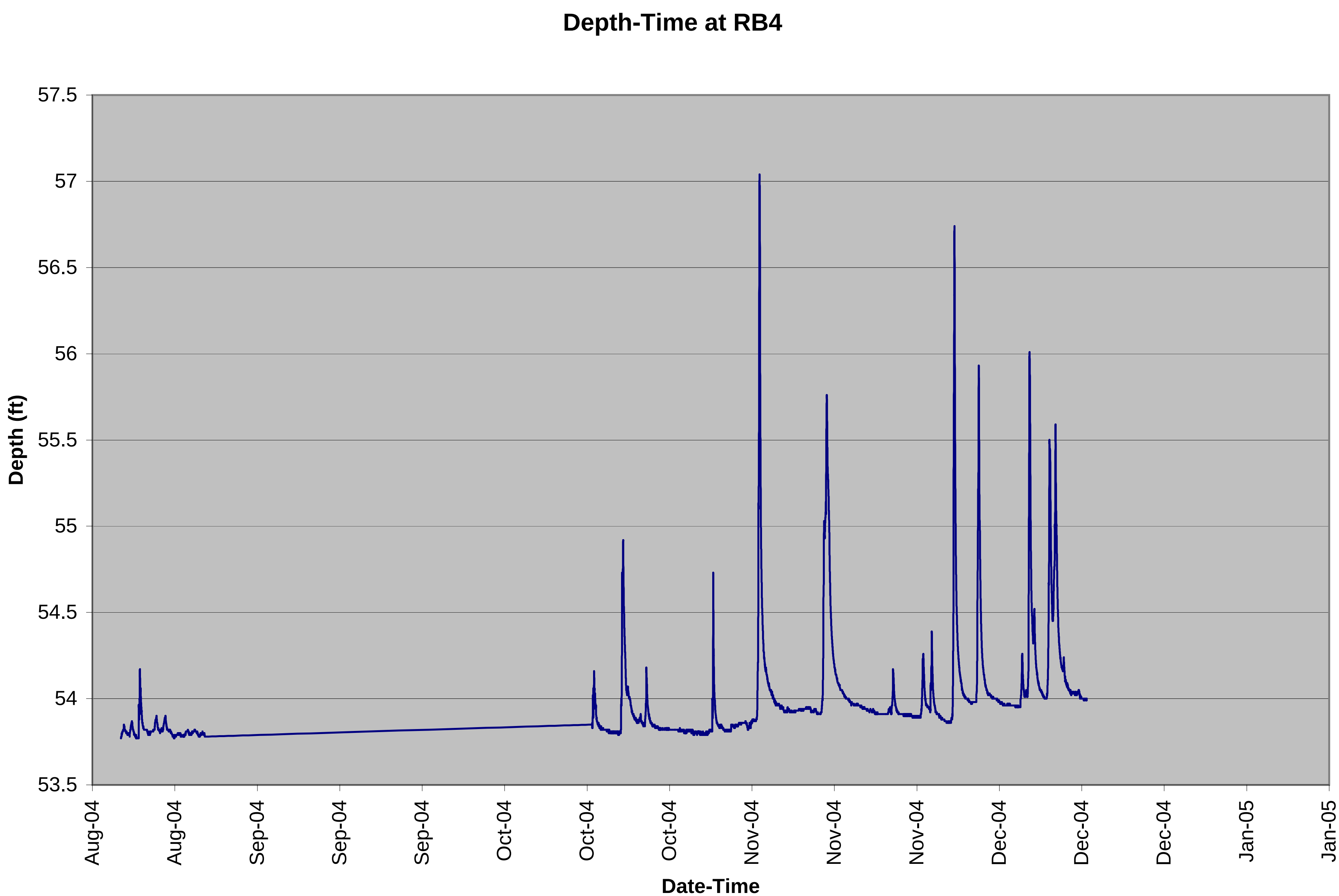

RB5 Flow vs. Date
Flow (cfs)
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Jun-04
Aug-04
Sep-04
Nov-04
Dec-04
Feb-05
Apr-05
May-05
Jul-05
Date

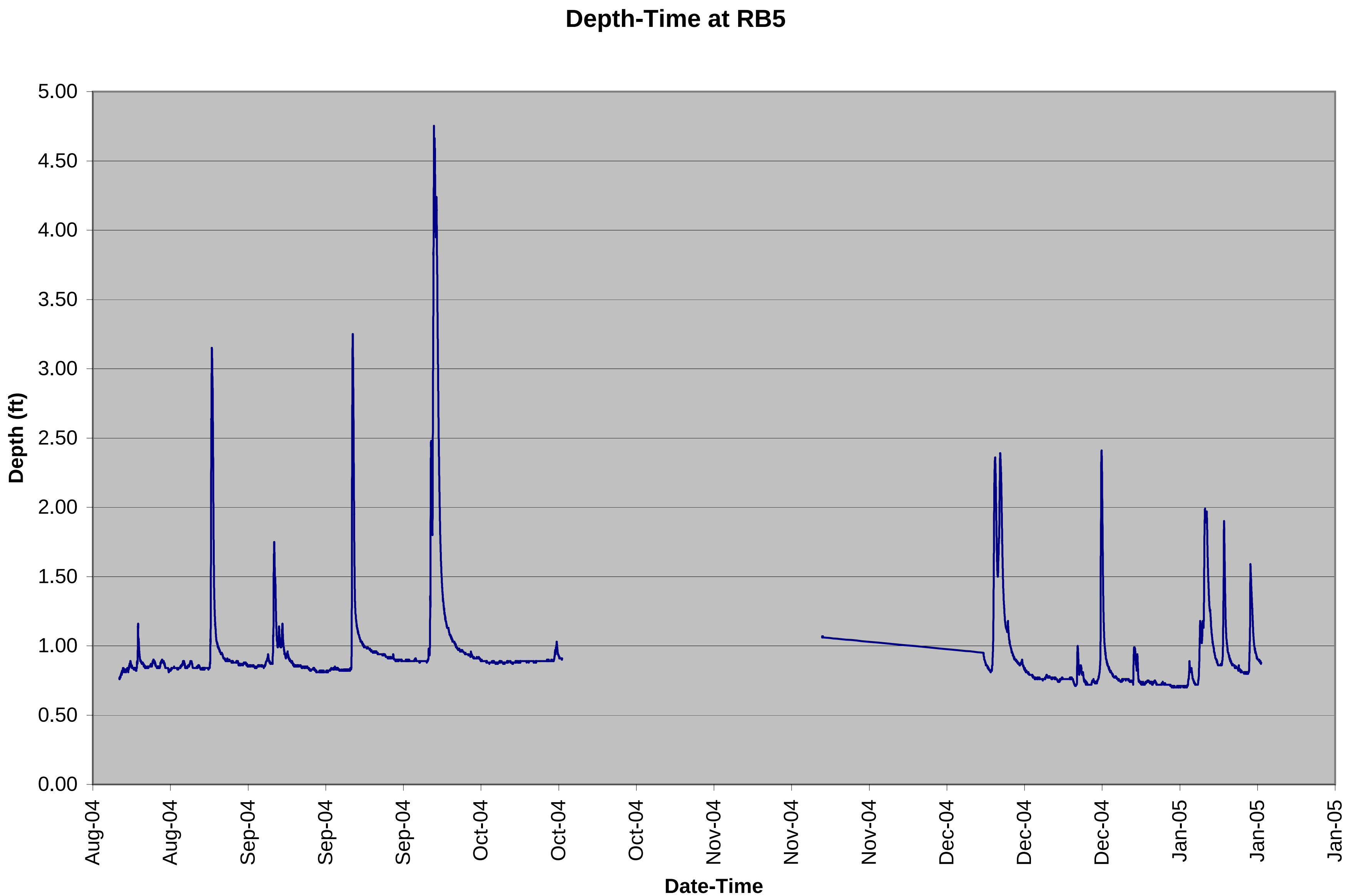

Depth-Time at RB1
Depth (ft)
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Aug-04
Aug-04
Sep-04
Sep-04
Sep-04
Oct-04
Oct-04
Oct-04
Nov-04
Nov-04
Nov-04
Dec-04
Dec-04
Dec-04
Jan-05
Jan-05
Date-Time


Depth-Time at RB2
Depth (ft)
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Aug-04
Aug-04
Sep-04
Sep-04
Sep-04
Oct-04
Oct-04
Oct-04
Nov-04
Nov-04
Nov-04
Dec-04
Dec-04
Dec-04
Jan-05
Jan-05
Jan-05
Date-Time

Depth-Time at RB3




Depth-Time at RB4
Depth (ft)
57.5
57
56.5
56
55.5
55
54.5
54
53.5
Aug-04
Aug-04
Sep-04
Sep-04
Sep-04
Oct-04
Oct-04
Oct-04
Nov-04
Nov-04
Nov-04
Dec-04
Dec-04
Dec-04
Jan-05
Jan-05
Date-Time


Depth-Time at RB5
Depth (ft)
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Aug-04
Aug-04
Sep-04
Sep-04
Sep-04
Oct-04
Oct-04
Oct-04
Nov-04
Nov-04
Nov-04
Dec-04
Dec-04
Dec-04
Jan-05
Jan-05
Jan-05
Date-Time

APPENDIX D: Sediment Sampling Data

NJ AGRICULTURAL EXPERIMENT STATION
RUTGERS
COOPERATIVE RESEARCH & EXTENSION

Rutgers Soil Testing Laboratory
P.O. Box 902
Milltown, NJ 08850
(732) 932-9295

Soil Test Report

TRL Omni Environmental
Mike Wright
321 Wall Street
Princeton, NJ 08540

Date Reported: **07/15/2005**
Date Received: 07/06/2005

LabNo Sample ID

5147 RB3 Bank

Sample Larger Than Sand = 15.6%
Mechanical Analysis:
Sand = 80%,
Silt = 10%,
Clay = 10%,
Texture = Loamy Sand

Sand Sieve Analysis:
Very Coarse Sand = 2.4%,
Coarse Sand = 4.8%,
Medium Sand = 36.9%,
Fine Sand = 49.9%,
Very Fine Sand = 6.1%

Estimated Permeability Class Rating = K4 (6 to 20 in/hr)

5148 RB5 Sediment

Sample Larger Than Sand = 1.1%
Mechanical Analysis:
Sand = 96%,
Silt = 1%,
Clay = 3%,
Texture = Sand

Sand Sieve Analysis:
Very Coarse Sand = 4.1%,
Coarse Sand = 22.7%,
Medium Sand = 58.0%,
Fine Sand = 14.4%,
Very Fine Sand = 0.9%

Estimated Permeability Class Rating = K5 (>20 in/hr)

Sample Information

Lab ID: NJAL # 14350-01	**TRC OMNI Environmental** **Ramanessin Brook** **Project No. 6000** **Composite : RB1 Bank**	**Date Sampled: 5/3/05** **Time Sampled: 1337 hrs.** **Sampled by: TRC OMNI** **Date Received: 5/4/05**

Parameter	Result	Detection Limit	Units	Dilution	Method Code
Phosphorus, total as P	136	5.0	mg/kg	250	EPA 365.2
Iron			mg/kg	1	EPA 236.1
Total Solids		0.1	% by weight	NA	EPA 160.3

ND:Not Detected above Detection Limit

NA-Not Applicable

Results are expressed on a dry weight basis

George Latham — Date

Laboratory Director

Laboratory ID # 11005

Sample Information

Lab ID: NJAL # 14350-02	**TRC OMNI Environmental** **Ramanessin Brook** **Project No. 6000** **Composite : RB1 Sediment**	**Date Sampled: 5/3/05** **Time Sampled: 1345 hrs.** **Sampled by: TRC OMNI** **Date Received: 5/4/05**

Parameter	Result	Detection Limit	Units	Dilution	Method Code
Phosphorus, total as P	134	5.0	mg/kg	250	EPA 365.2
Iron			mg/kg	1	EPA 236.1
Total Solids		0.1	% by weight	NA	EPA 160.3

ND:Not Detected above Detection Limit

NA-Not Applicable

Results are expressed on a dry weight basis

George Latham Date

Laboratory Director

Laboratory ID # 11005

Sample Information

Lab ID: NJAL # 14350-03	**TRC OMNI Environmental**	**Date Sampled: 5/3/05**
	Ramanessin Brook	**Time Sampled: 1425 hrs.**
	Project No. 6000	**Sampled by: TRC OMNI**
	Composite : RB2 Bank	**Date Received: 5/4/05**

Parameter	Result	Detection Limit	Units	Dilution	Method Code
Phosphorus, total as P	148	5.0	mg/kg	250	EPA 365.2
Iron			mg/kg	1	EPA 236.1
Total Solids		0.1	% by weight	NA	EPA 160.3

ND:Not Detected above Detection Limit

NA-Not Applicable

Results are expressed on a dry weight basis

George Latham — Date

Laboratory Director

Laboratory ID # 11005

Sample Information

Lab ID: NJAL # 14350-04	**TRC OMNI Environmental**	**Date Sampled: 5/3/05**
	Ramanessin Brook	**Time Sampled: 1415 hrs.**
	Project No. 6000	**Sampled by: TRC OMNI**
	Composite : RB2 Sediment	**Date Received: 5/4/05**

Parameter	**Result**	**Detection Limit**	**Units**	**Dilution**	**Method Code**
Phosphorus, total as P	136	5.0	mg/kg	250	EPA 365.2
Iron			mg/kg	1	EPA 236.1
Total Solids		0.1	% by weight	NA	EPA 160.3

ND:Not Detected above Detection Limit

NA-Not Applicable

Results are expressed on a dry weight basis

Laboratory ID # 11005

George Latham — Date

Laboratory Director

Sample Information

Lab ID: NJAL # 14350-05	TRC OMNI Environmental	Date Sampled: 5/3/05
	Ramanessin Brook	Time Sampled: 1255 hrs.
	Project No. 6000	Sampled by: TRC OMNI
	Composite : RB3 Bank	Date Received: 5/4/05

Parameter	Result	Detection Limit	Units	Dilution	Method Code
Phosphorus, total as P	157	5.0	mg/kg	250	EPA 365.2
Iron			mg/kg	1	EPA 236.1
Total Solids		0.1	% by weight	NA	EPA 160.3

ND:Not Detected above Detection Limit

NA-Not Applicable

Results are expressed on a dry weight basis

Laboratory ID # 11005

George Latham   Date

Laboratory Director

Sample Information

Lab ID: NJAL # 14350-06	TRC OMNI Environmental Ramanessin Brook Project No. 6000 Composite : RB3 Sediment	Date Sampled: 5/3/05 Time Sampled: 1247 hrs. Sampled by: TRC OMNI Date Received: 5/4/05

Parameter	Result	Detection Limit	Units	Dilution	Method Code
Phosphorus, total as P	145	5.0	mg/kg	250	EPA 365.2
Iron			mg/kg	1	EPA 236.1
Total Solids		0.1	% by weight	NA	EPA 160.3

ND:Not Detected above Detection Limit

NA-Not Applicable

Results are expressed on a dry weight basis

George Latham   Date

Laboratory Director

Laboratory ID # 11005

Sample Information

Lab ID: NJAL # 14350-07	**TRC OMNI Environmental**	**Date Sampled: 5/3/05**
	Ramanessin Brook	**Time Sampled: 1230 hrs.**
	Project No. 6000	**Sampled by: TRC OMNI**
	Composite : RB4 Bank	**Date Received: 5/4/05**

Parameter	Result	Detection Limit	Units	Dilution	Method Code
Fecal Coliform	ND	10	colonies/gram	10	SM 9222D
Phosphorus, total as P	152	5.0	mg/kg	250	EPA 365.2
Iron			mg/kg	1	EPA 236.1
Total Solids		0.1	% by weight	NA	EPA 160.3

ND:Not Detected above Detection Limit

NA-Not Applicable

Results are expressed on a dry weight basis

F. Coli Date Analyzed: 5/05/05

F. Coli Time Analyzed: 0845 hrs.

Laboratory ID # 11005

George Latham
Laboratory Director

Date

Sample Information

Lab ID: NJAL # 14350-08	**TRC OMNI Environmental**	**Date Sampled: 5/3/05**
	Ramanessin Brook	**Time Sampled: 1223 hrs.**
	Project No. 6000	**Sampled by: TRC OMNI**
	Composite : RB4 Sediment	**Date Received: 5/4/05**

Parameter	Result	Detection Limit	Units	Dilution	Method Code
Fecal Coliform	10	10	colonies/gram	10	SM 9222D
Phosphorus, total as P	167	5.0	mg/kg	250	EPA 365.2
Iron			mg/kg	1	EPA 236.1
Total Solids		0.1	% by weight	NA	EPA 160.3

ND:Not Detected above Detection Limit

NA-Not Applicable

Results are expressed on a dry weight basis

F. Coli Date Analyzed: 5/05/05

F. Coli Time Analyzed: 0845 hrs.

Laboratory ID # 11005

George Latham — Date

Laboratory Director

Sample Information

Lab ID: NJAL # 14350-09	**TRC OMNI Environmental**	**Date Sampled: 5/3/05**
	Ramanessin Brook	**Time Sampled: 1040 hrs.**
	Project No. 6000	**Sampled by: TRC OMNI**
	Composite : RB5 Bank	**Date Received: 5/4/05**

Parameter	**Result**	**Detection Limit**	**Units**	**Dilution**	**Method Code**
Phosphorus, total as P	136	5.0	mg/kg	250	EPA 365.2
Iron			mg/kg	1	EPA 236.1
Total Solids		0.1	% by weight	NA	EPA 160.3

ND:Not Detected above Detection Limit

NA-Not Applicable

Results are expressed on a dry weight basis

George Latham — Date

Laboratory Director

Laboratory ID # 11005

Sample Information

Lab ID: NJAL # 14350-10	**TRC OMNI Environmental**	**Date Sampled:** 5/3/05
	Ramanessin Brook	**Time Sampled:** 1025 hrs.
	Project No. 6000	**Sampled by:** TRC OMNI
	Composite : RB5 Sediment	**Date Received:** 5/4/05

Parameter	Result	Detection Limit	Units	Dilution	Method Code
Phosphorus, total as P	129	5.0	mg/kg	250	EPA 365.2
Iron			mg/kg	1	EPA 236.1
Total Solids		0.1	% by weight	NA	EPA 160.3

ND:Not Detected above Detection Limit

NA-Not Applicable

Results are expressed on a dry weight basis

George Latham — Date

Laboratory Director

Laboratory ID # 11005

APPENDIX E: New Jersey Rainfall Tables

USDA Natural Resources Conservation Service
New Jersey State Office
220 Davidson Ave., Somerset, NJ 08873
Tel. 732-537-6056 Fax 732-537-6095

NEW JERSEY 24 HOUR RAINFALL FREQUENCY DATA

Rainfall amounts in Inches

County	1 year	2 year	5 year	10 year	25 year	50 year	100 year
Atlantic	2.8	3.3	4.3	5.2	6.5	7.6	8.9
Bergen	2.8	3.3	4.3	5.1	6.3	7.3	8.4
Burlington	2.8	3.4	4.3	5.2	6.4	7.6	8.8
Camden	2.8	3.3	4.3	5.1	6.3	7.3	8.5
Cape May	2.8	3.3	4.2	5.1	6.4	7.5	8.8
Cumberland	2.8	3.3	4.2	5.1	6.4	7.5	8.8
Essex	2.8	3.4	4.4	5.2	6.4	7.5	8.7
Gloucester	2.8	3.3	4.2	5.0	6.2	7.3	8.5
Hudson	2.7	3.3	4.2	5.0	6.2	7.2	8.3
Hunterdon	2.9	3.4	4.3	5.0	6.1	7.0	8.0
Mercer	2.8	3.3	4.2	5.0	6.2	7.2	8.3
Middlesex	2.8	3.3	4.3	5.1	6.4	7.4	8.6
Monmouth	2.9	3.4	4.4	5.2	6.5	7.7	8.9
Morris	3.0	3.5	4.5	5.2	6.3	7.3	8.3
Ocean	3.0	3.4	4.5	5.4	6.7	7.9	9.2
Passaic	3.0	3.5	4.4	5.3	6.5	7.5	8.7
Salem	2.8	3.3	4.2	5.0	6.2	7.3	8.5
Somerset	2.8	3.3	4.3	5.0	6.2	7.2	8.2
Sussex	2.7	3.2	4.0	4.7	5.7	6.6	7.6
Union	2.8	3.4	4.4	5.2	6.4	7.5	8.7
Warren	2.8	3.3	4.2	4.9	5.9	6.8	7.8

APPENDIX F: Hydraulic and Pollutant Loading Modeling Analyses

Peak Flow Analysis for 1-Year Storm (Pre-Developed/Current/Build-Out Conditions)

Peak Flow Analysis for 2-Year Storm (Pre-Developed/Current/Build-Out Conditions)

Peak Flow Analysis for 10-Year Storm (Pre-Developed/Current/Build-Out Conditions)

Peak Flow Analysis for 100-Year Storm (Pre-Developed/Current/Build-Out Conditions)

Total Volume Analysis for 1-Year Storm (Pre-Developed/Current/Build-Out Conditions)

Total Volume Analysis for 2-Year Storm (Pre-Developed/Current/Build-Out Conditions)

Total Volume Analysis for 10-Year Storm (Pre-Developed/Current/Build-Out Conditions)

Total Volume Analysis for 100-Year Storm (Pre-Developed/Current/Build-Out Conditions)

Total Shear Stress Analysis for 2-Year Storm (Pre-Developed/Current/Build-Out Conditions)

TSS Loading Analysis for 2-Year Storm (Pre-Developed/Current/Build-Out Conditions)

TSS Loading Estimate for 2-Year Storm (Total Load and Total Normalized Load)

TP Loading Analysis for 2-Year Storm (Pre-Developed/Current/Build-Out Conditions)

TP Loading Estimate for 2-Year Storm (Total Load and Total Normalized Load)

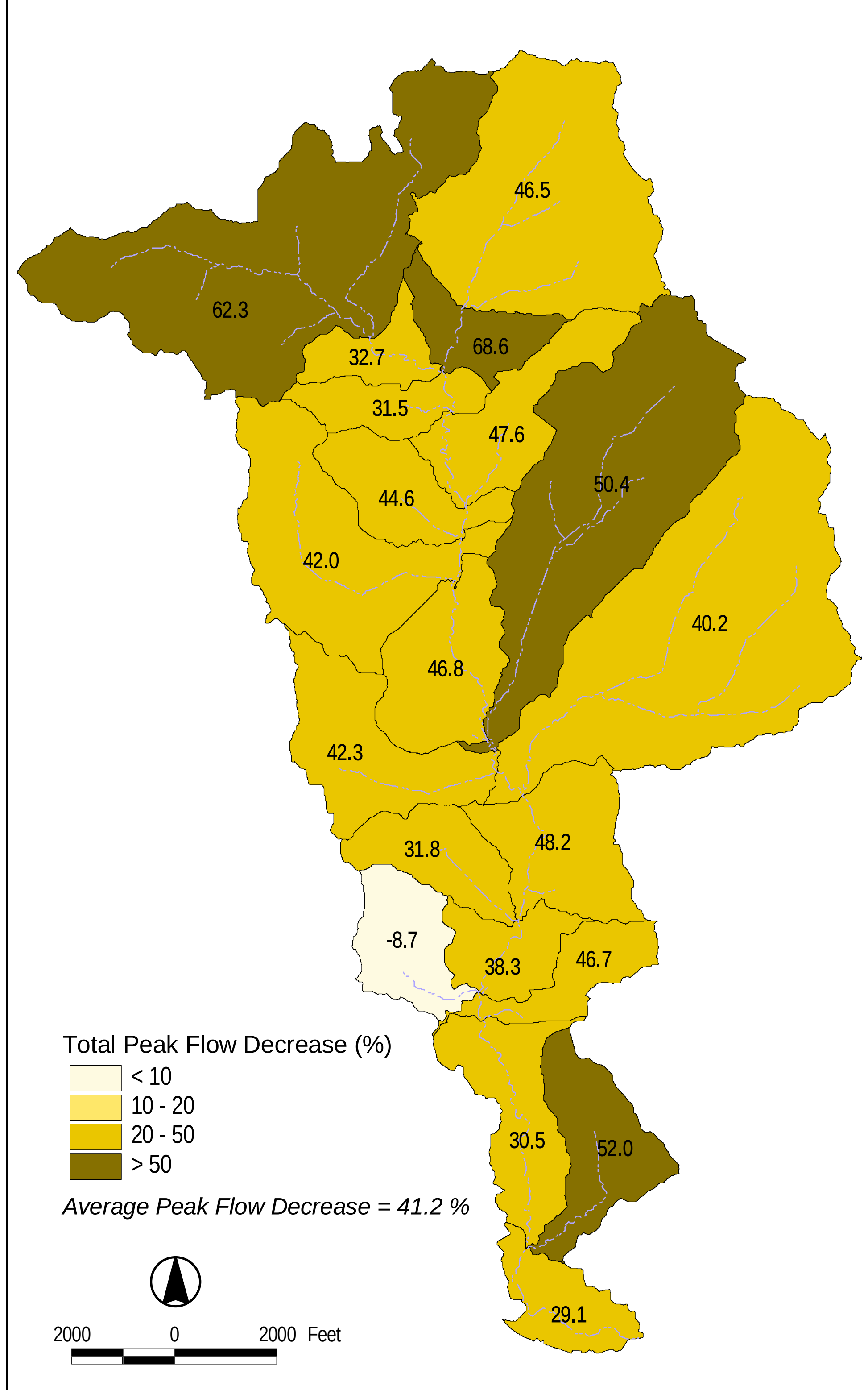
FC Loading Analysis for 2-Year Storm (Pre-Developed/Current/Build-Out Conditions)

FC Loading Estimate for 2-Year Storm (Total Load and Total Normalized Load)

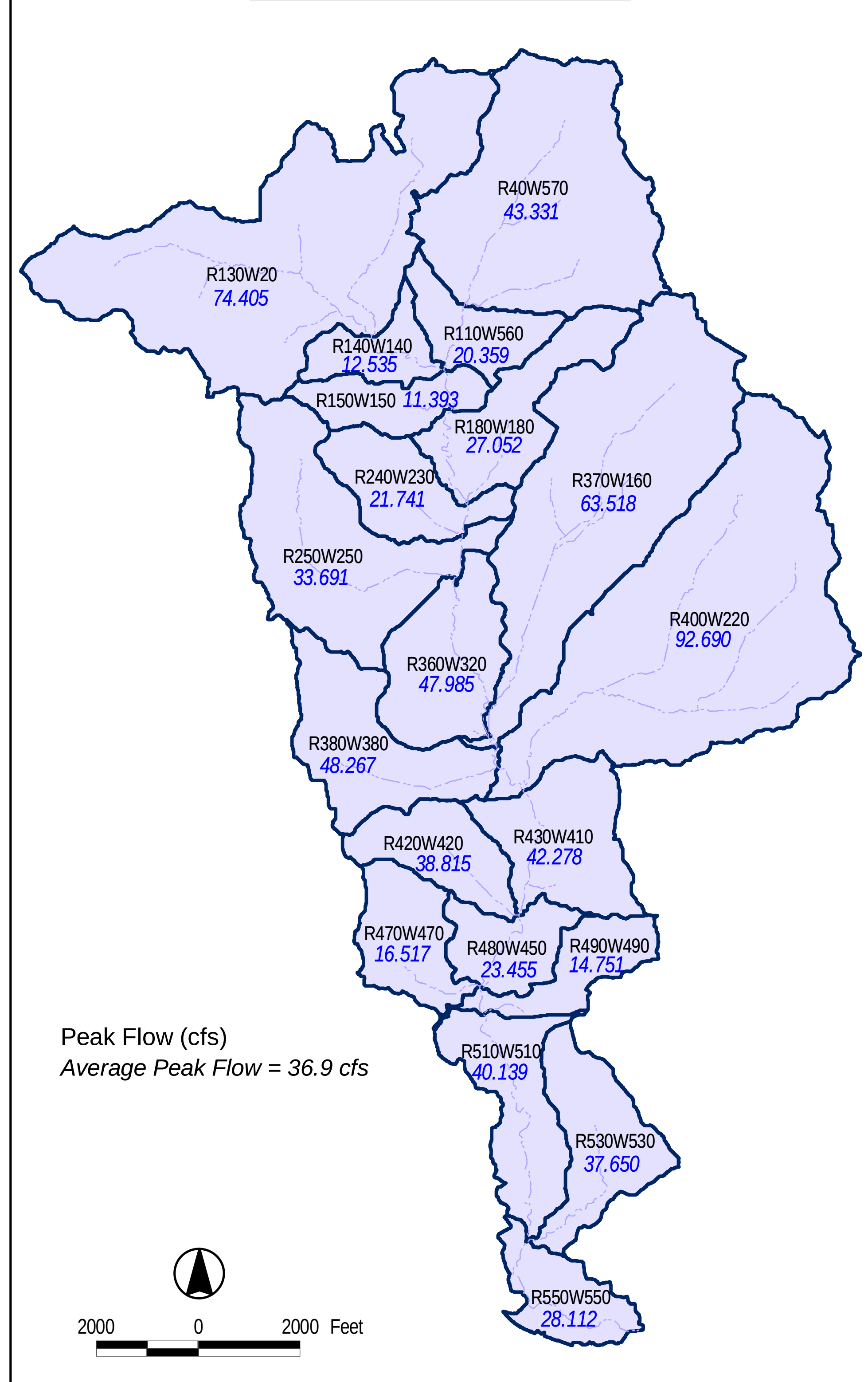
Ramanessin Brook NPS Pollution Source Assessment and Stormwater Impact Study

Peak Flow Analysis - 1 Year Storm

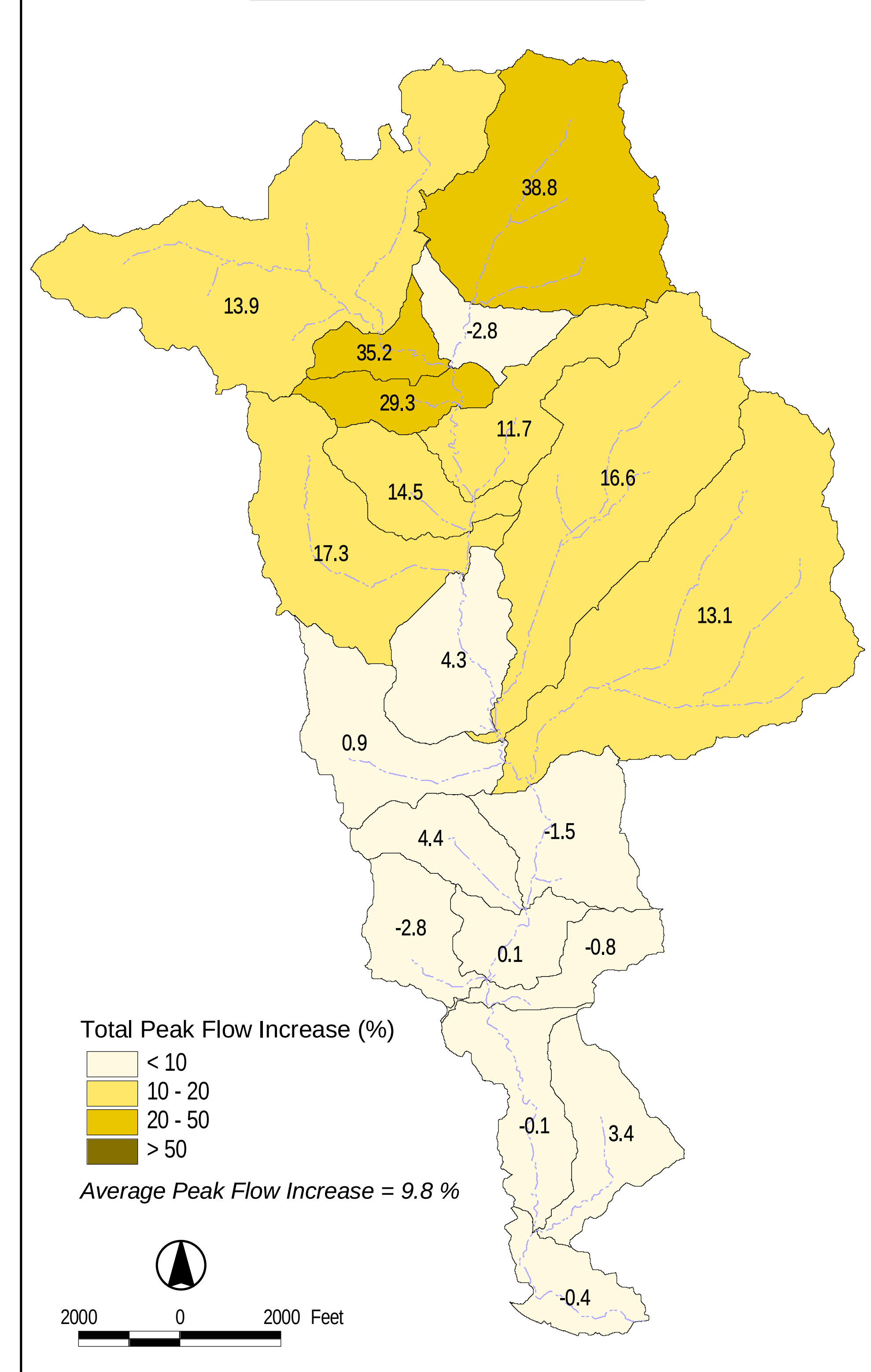
Pre-Developed Conditions



Existing Conditions



Build-Out Conditions

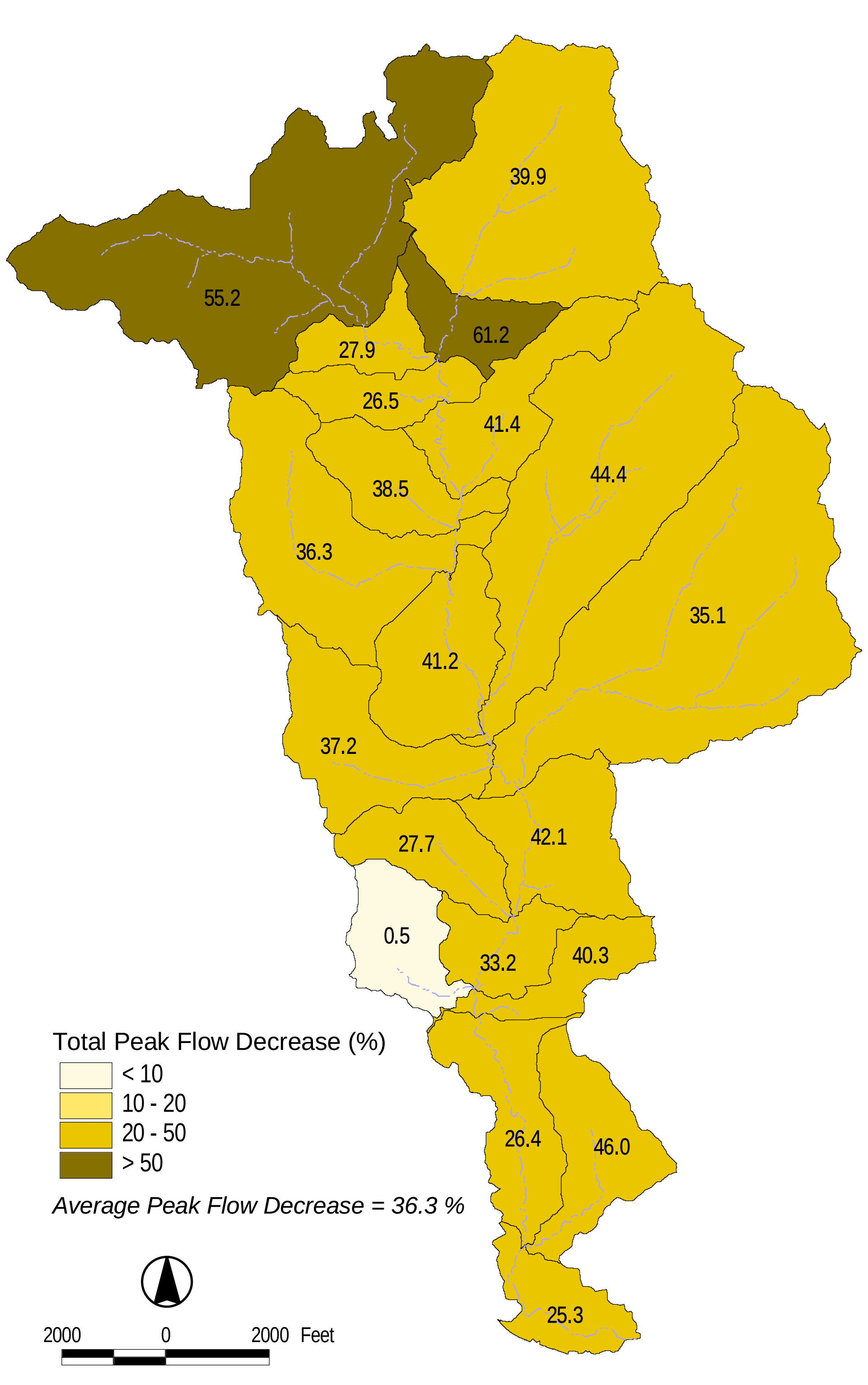


TRC Omni Environmental Corporation

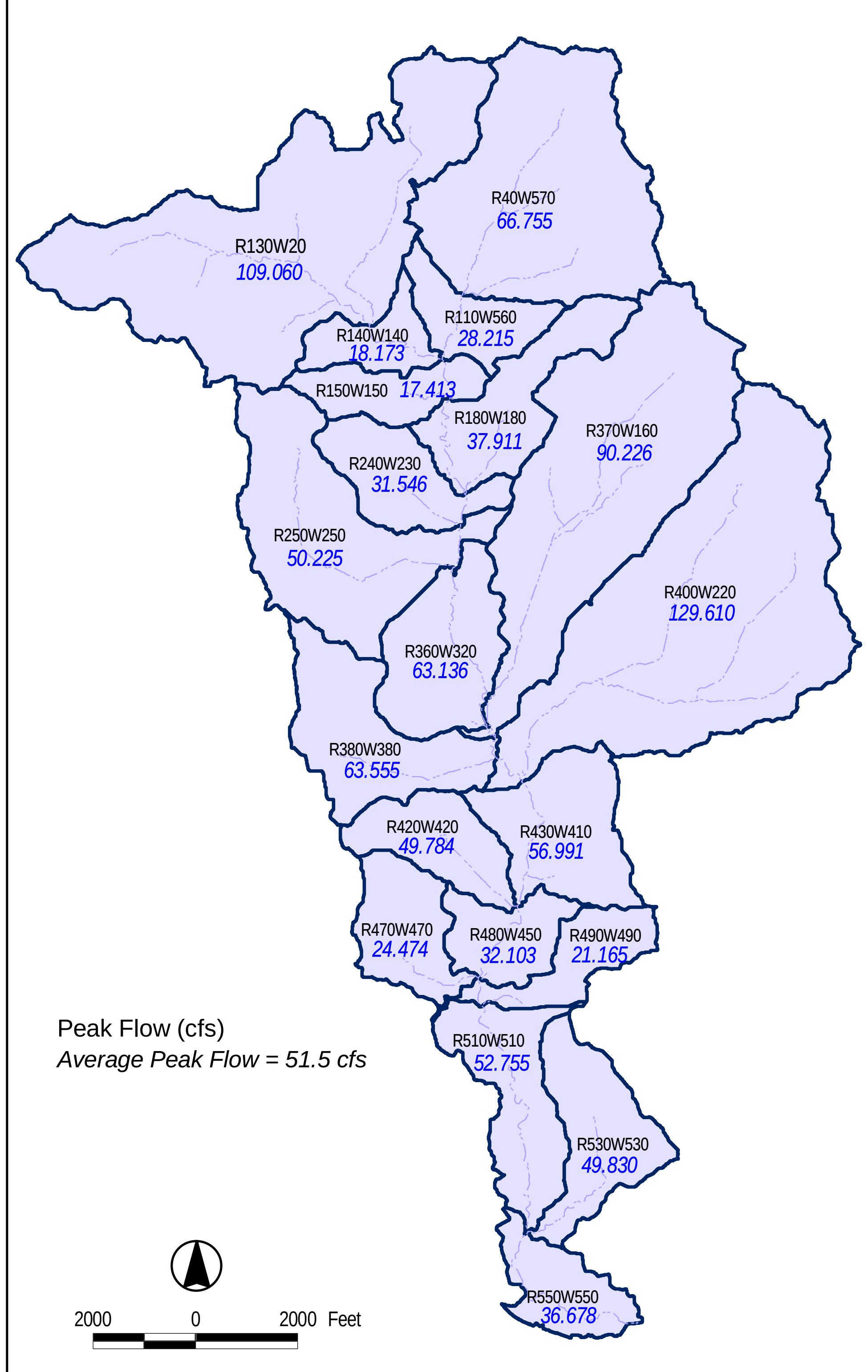
Ramanessin Brook NPS Pollution Source Assessment and Stormwater Impact Study

Peak Flow Analysis - 2 Year Storm

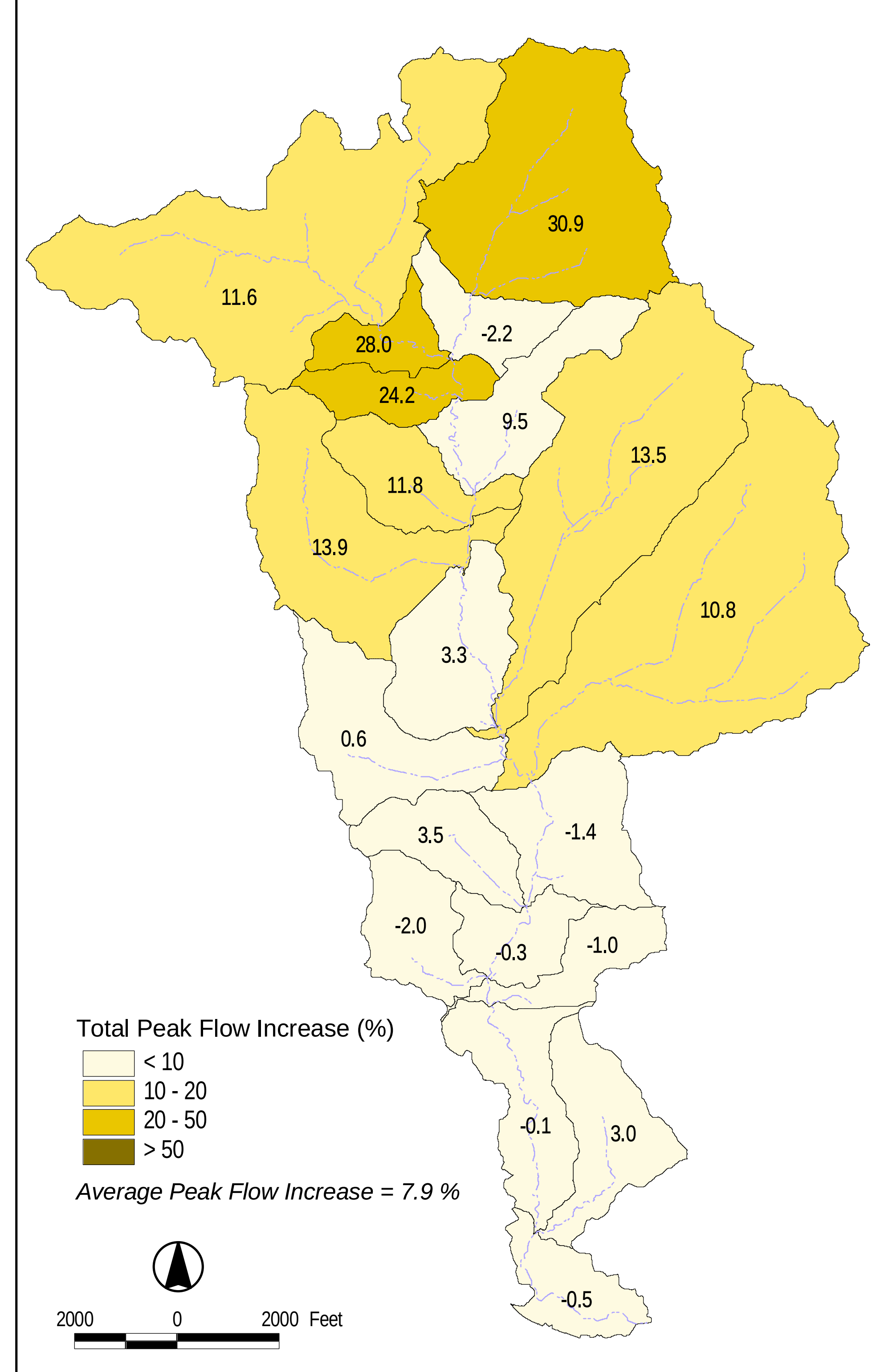
Pre-Developed Conditions



Existing Conditions



Build-Out Conditions

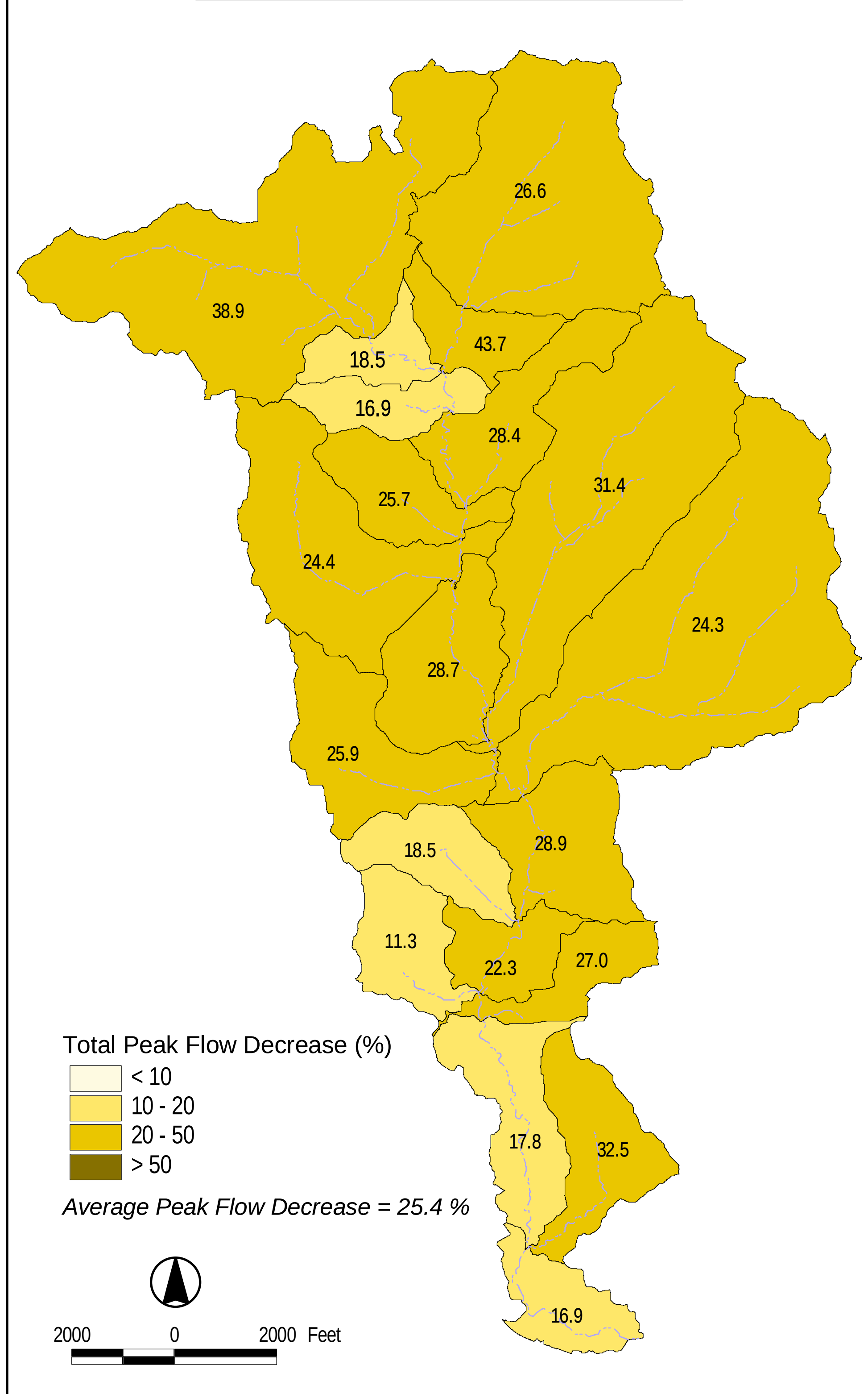


TRC Omni Environmental Corporation

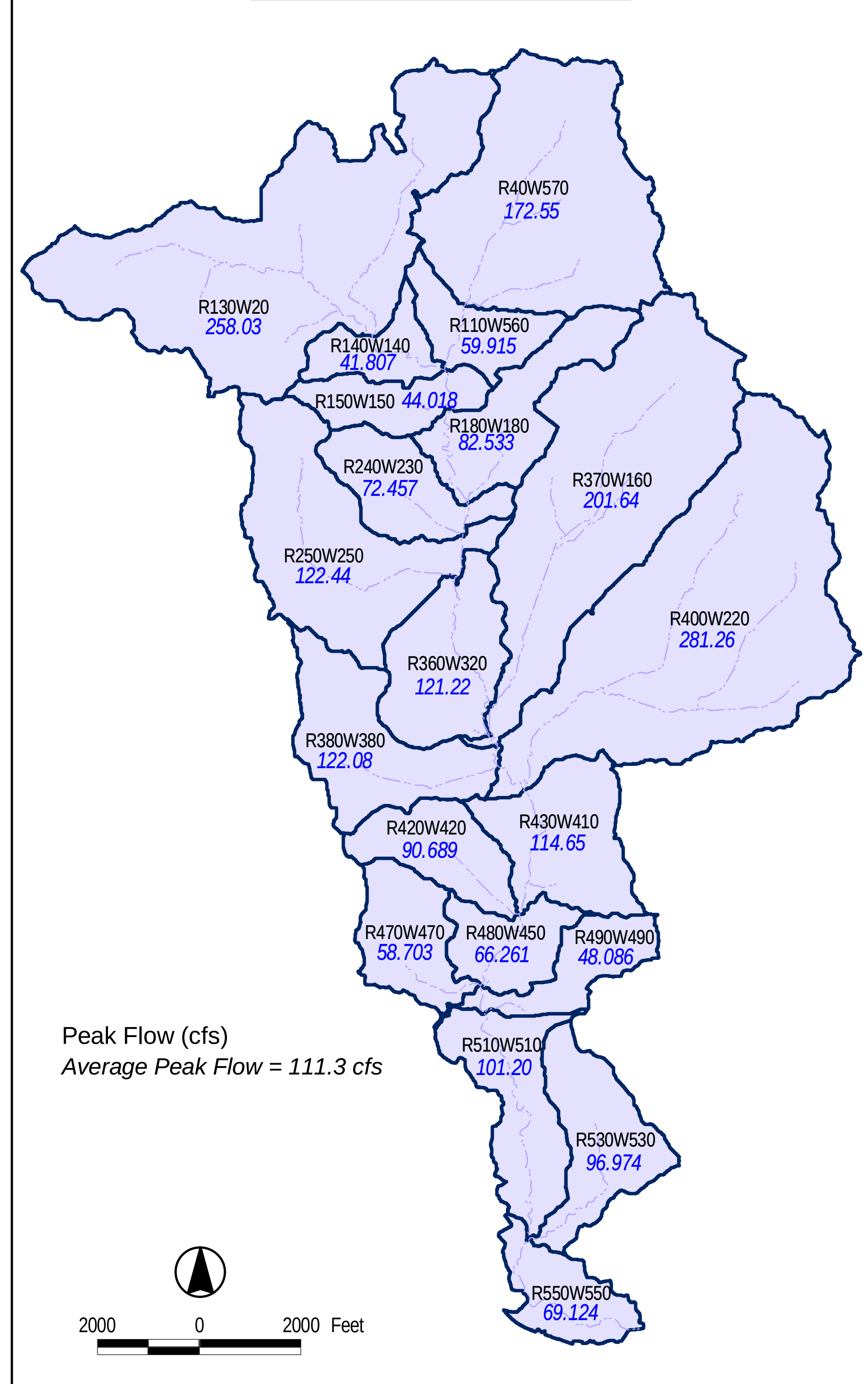
Ramanessin Brook NPS Pollution Source Assessment and Stormwater Impact Study

Peak Flow Analysis - 10 Year Storm

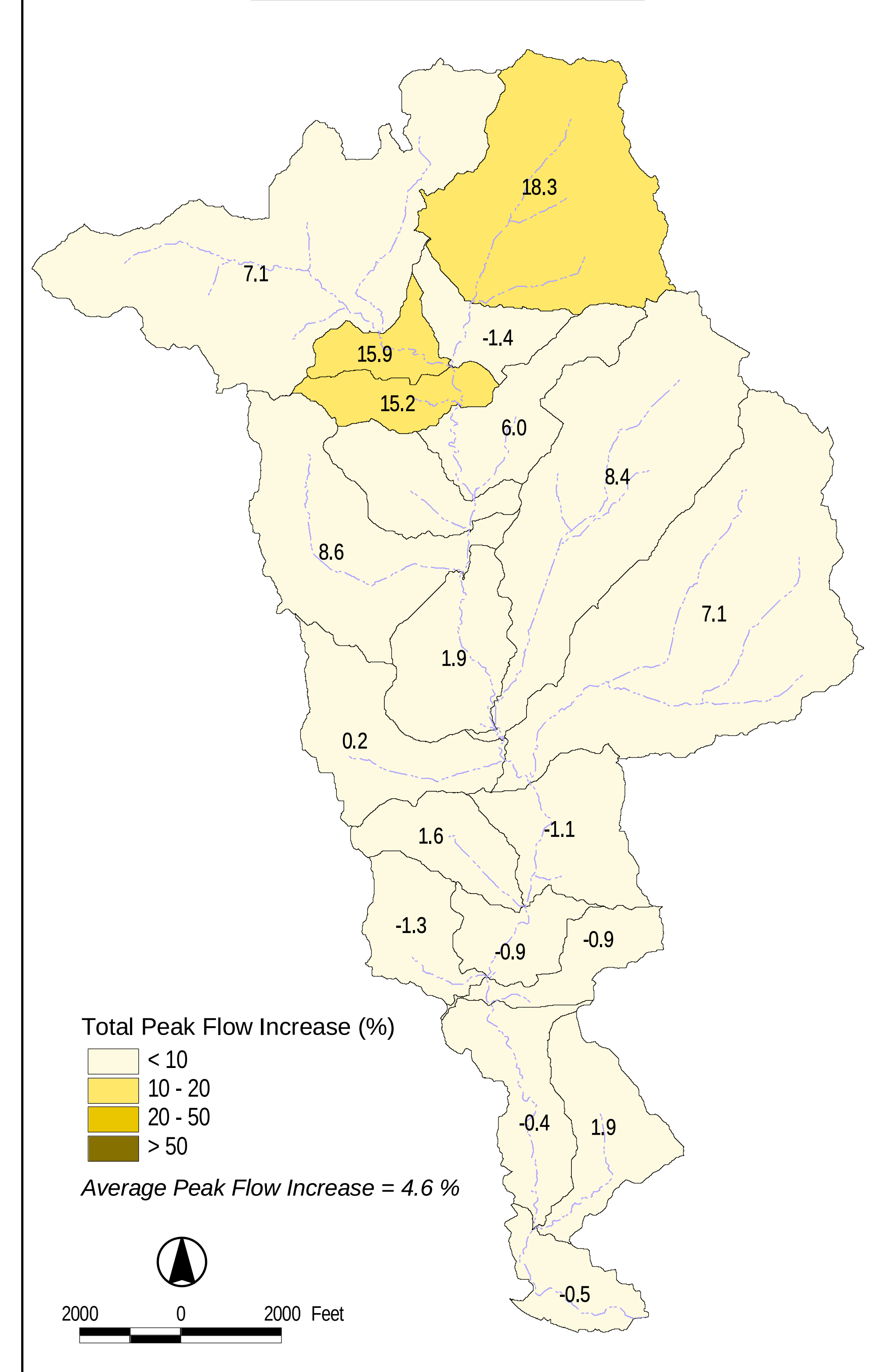
Pre-Developed Conditions



Existing Conditions



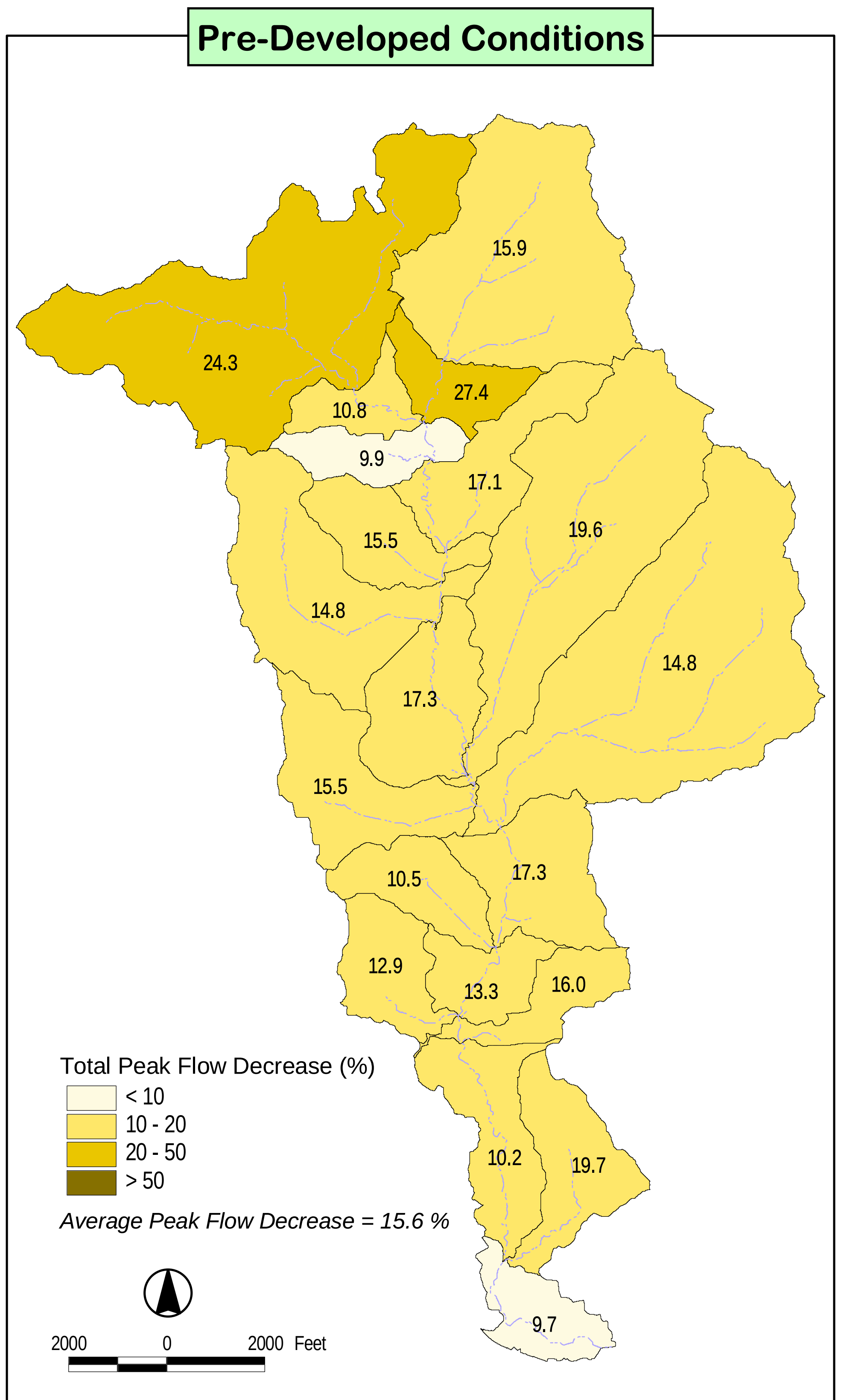
Build-Out Conditions

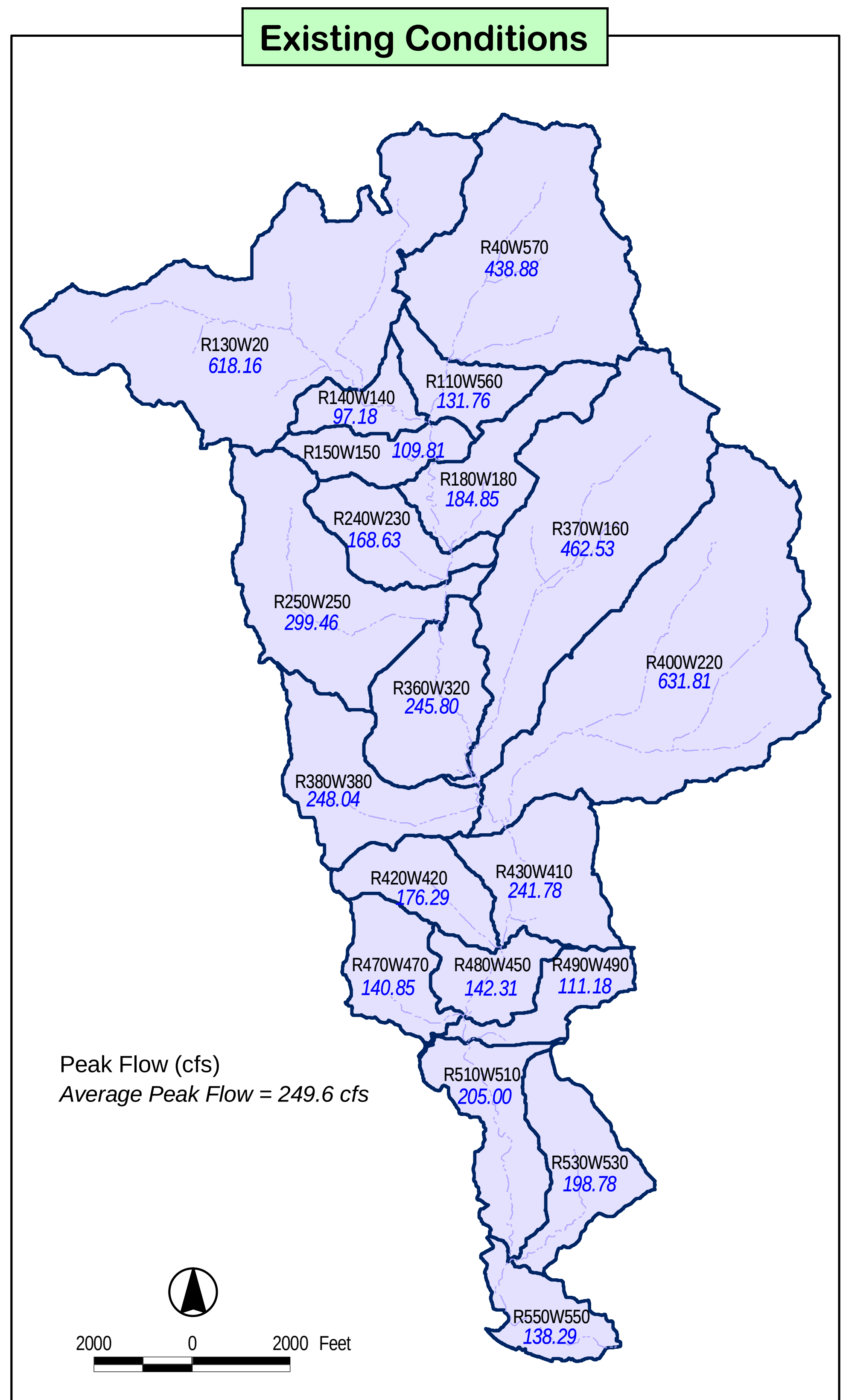


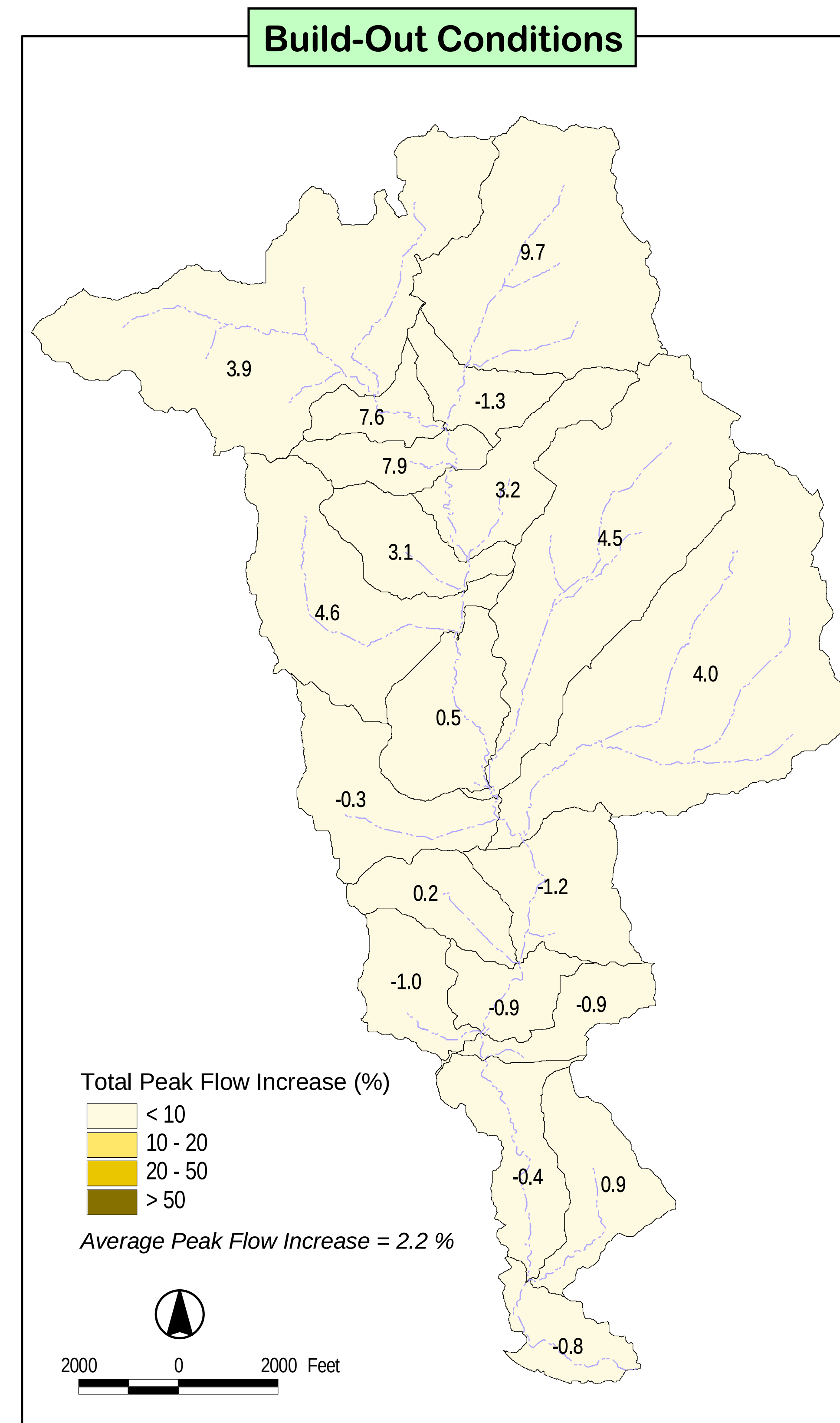
TRC Omni Environmental Corporation

Ramanessin Brook NPS Pollution Source Assessment and Stormwater Impact Study

Peak Flow Analysis - 100 Year Storm



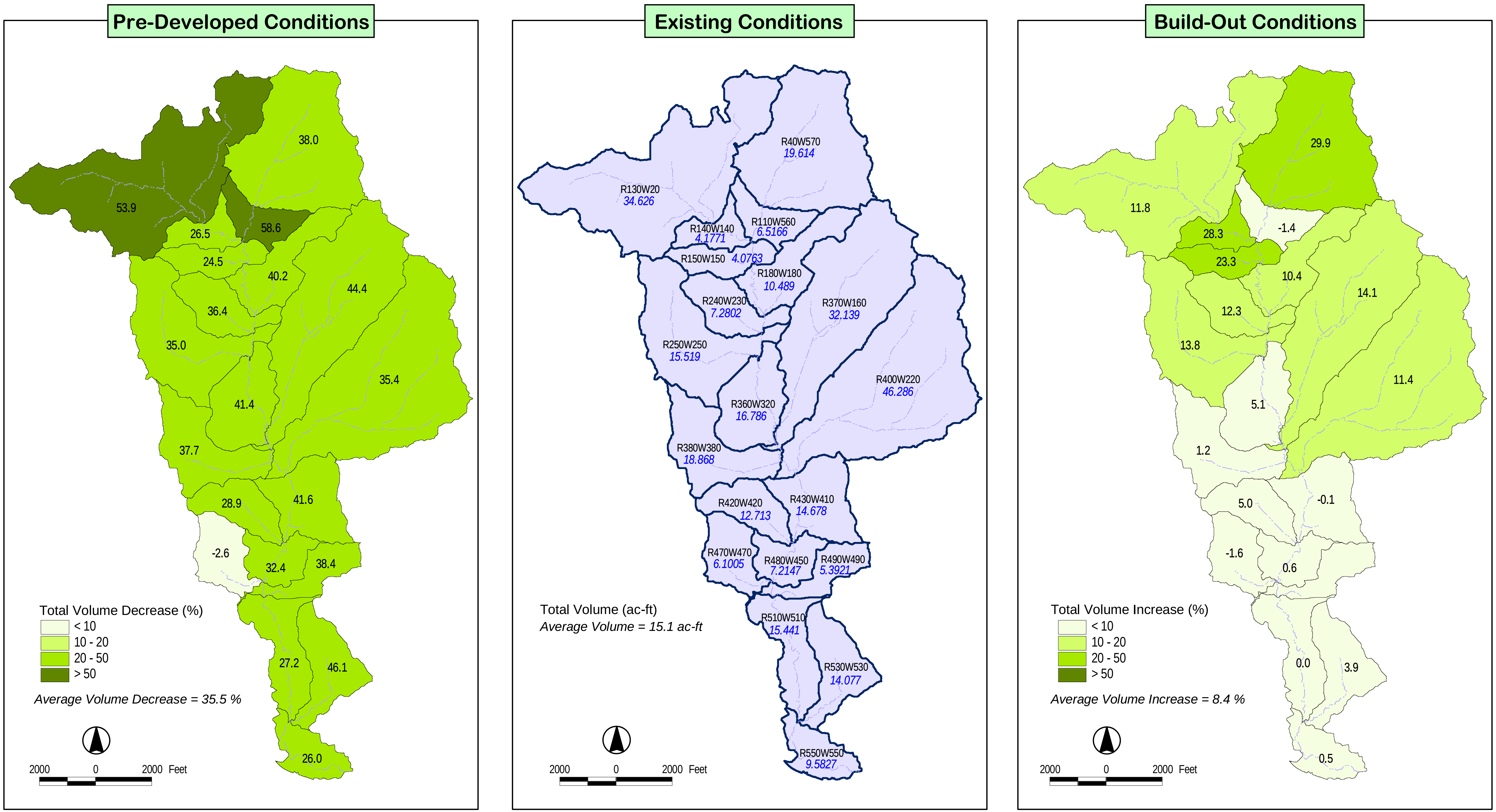




TRC Omni Environmental Corporation

Ramanessin Brook NPS Pollution Source Assessment and Stormwater Impact Study

Total Volume Analysis - 1 Year Storm

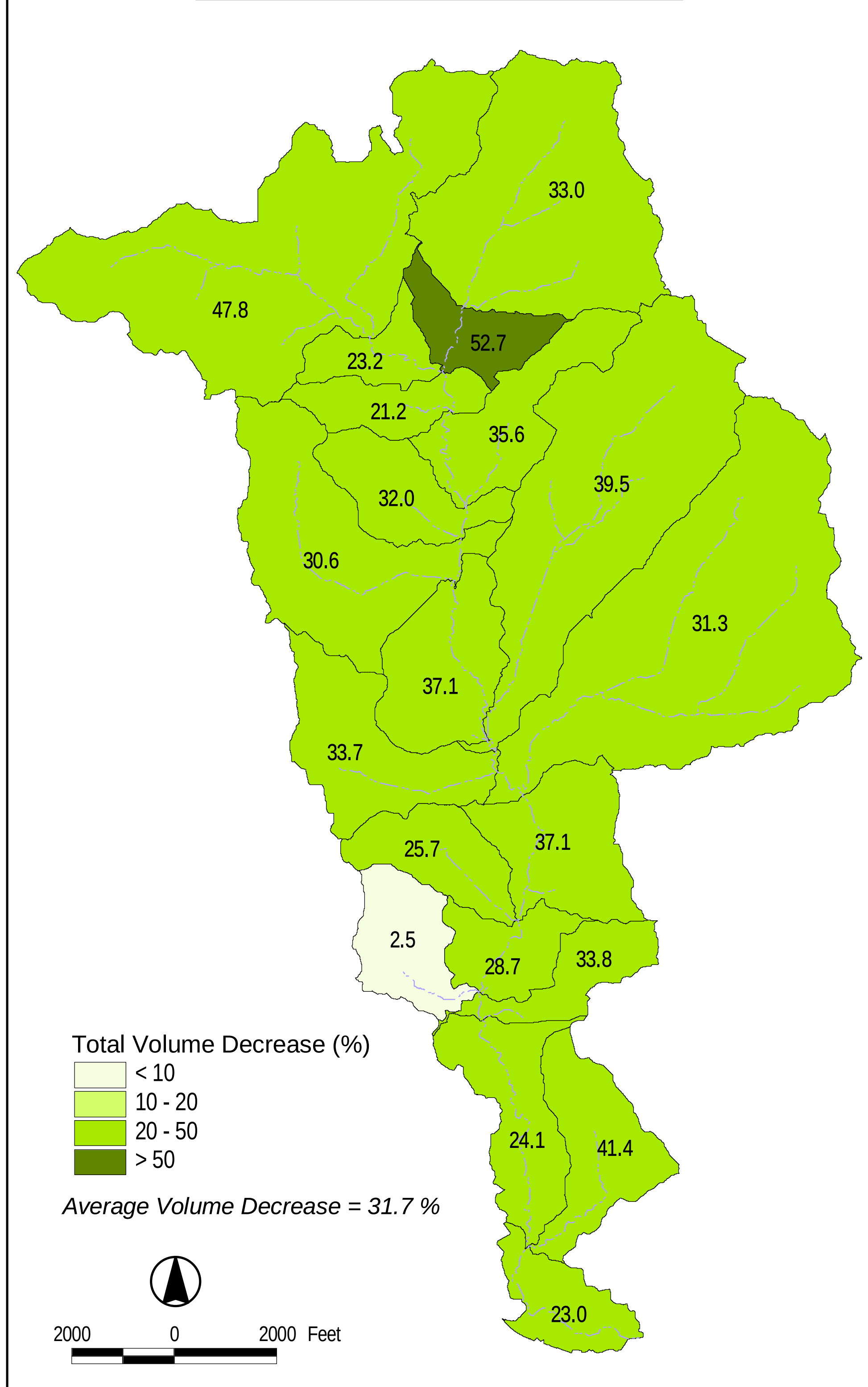


TRC Omni Environmental Corporation

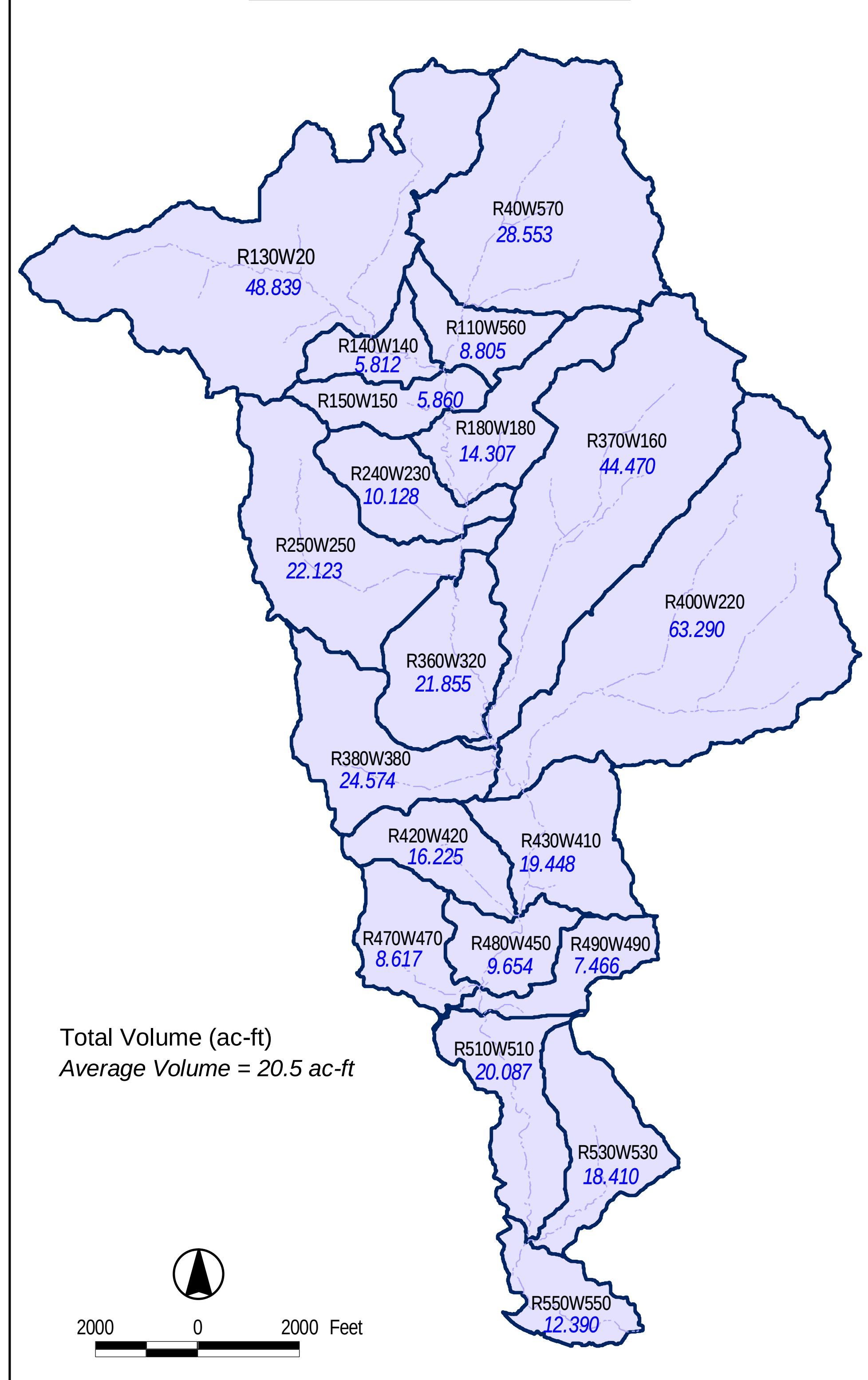
Ramanessin Brook NPS Pollution Source Assessment and Stormwater Impact Study

Total Volume Analysis - 2 Year Storm

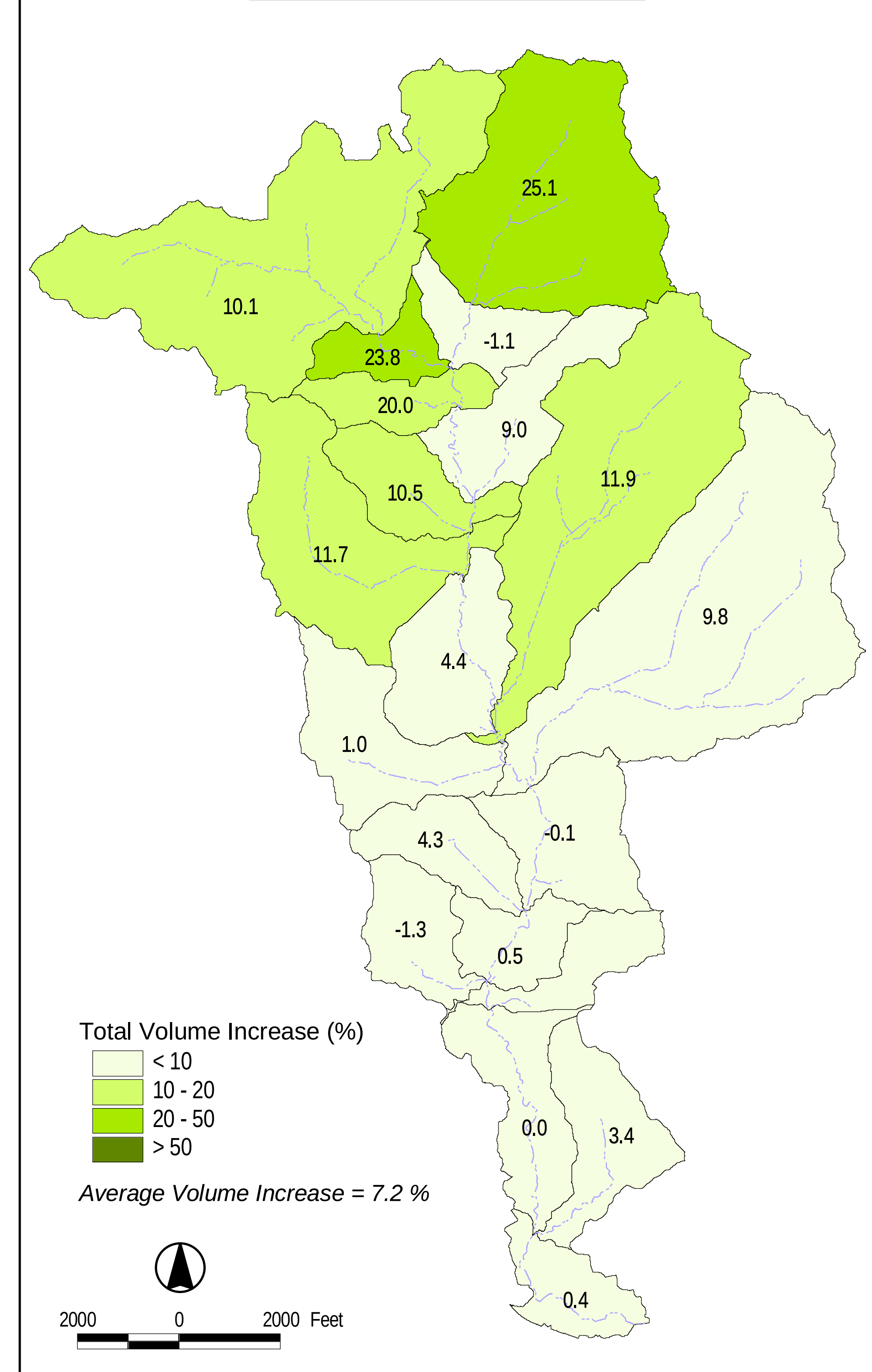
Pre-Developed Conditions



Existing Conditions



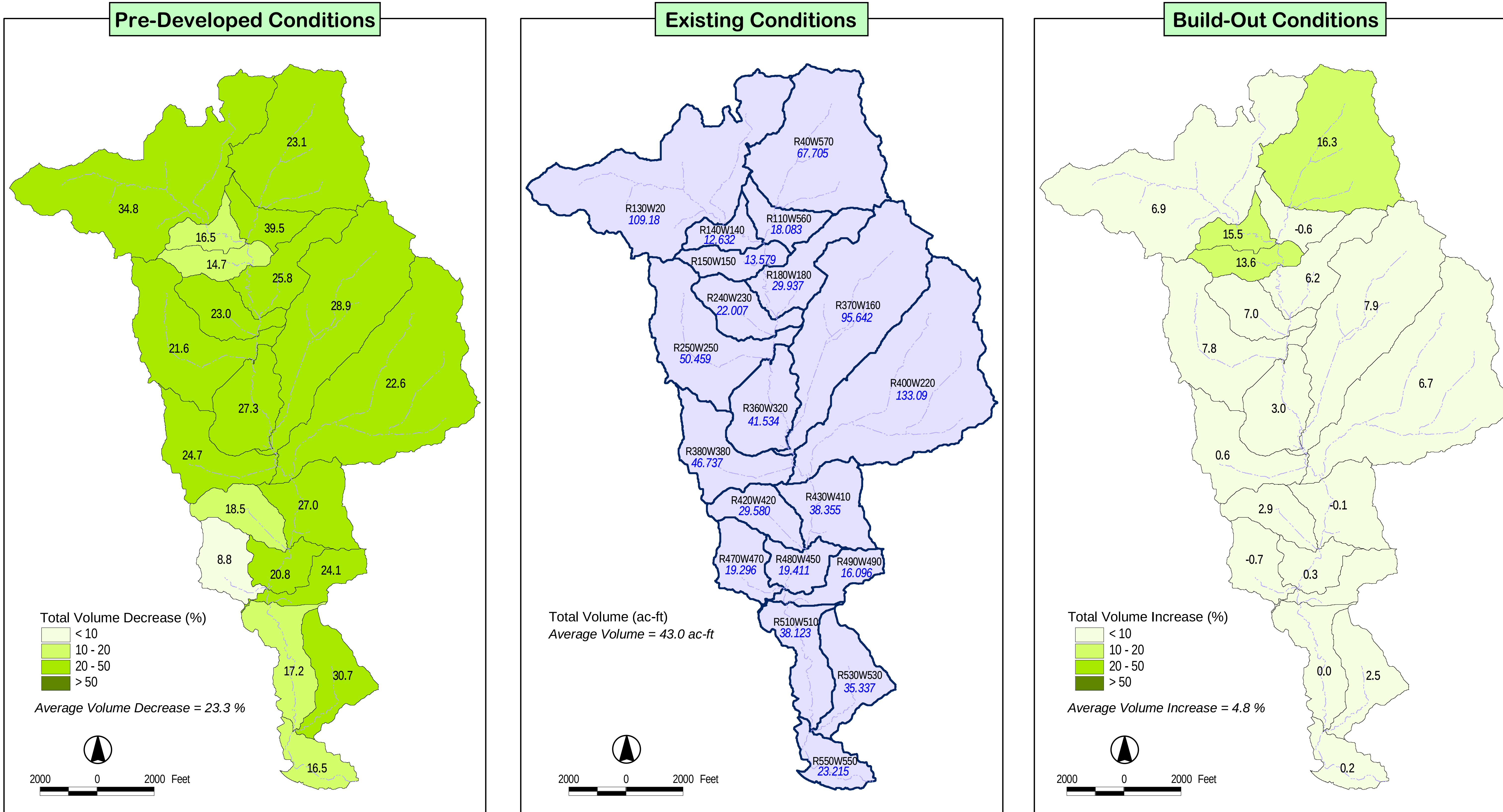
Build-Out Conditions



TRC Omni Environmental Corporation

Ramanessin Brook NPS Pollution Source Assessment and Stormwater Impact Study

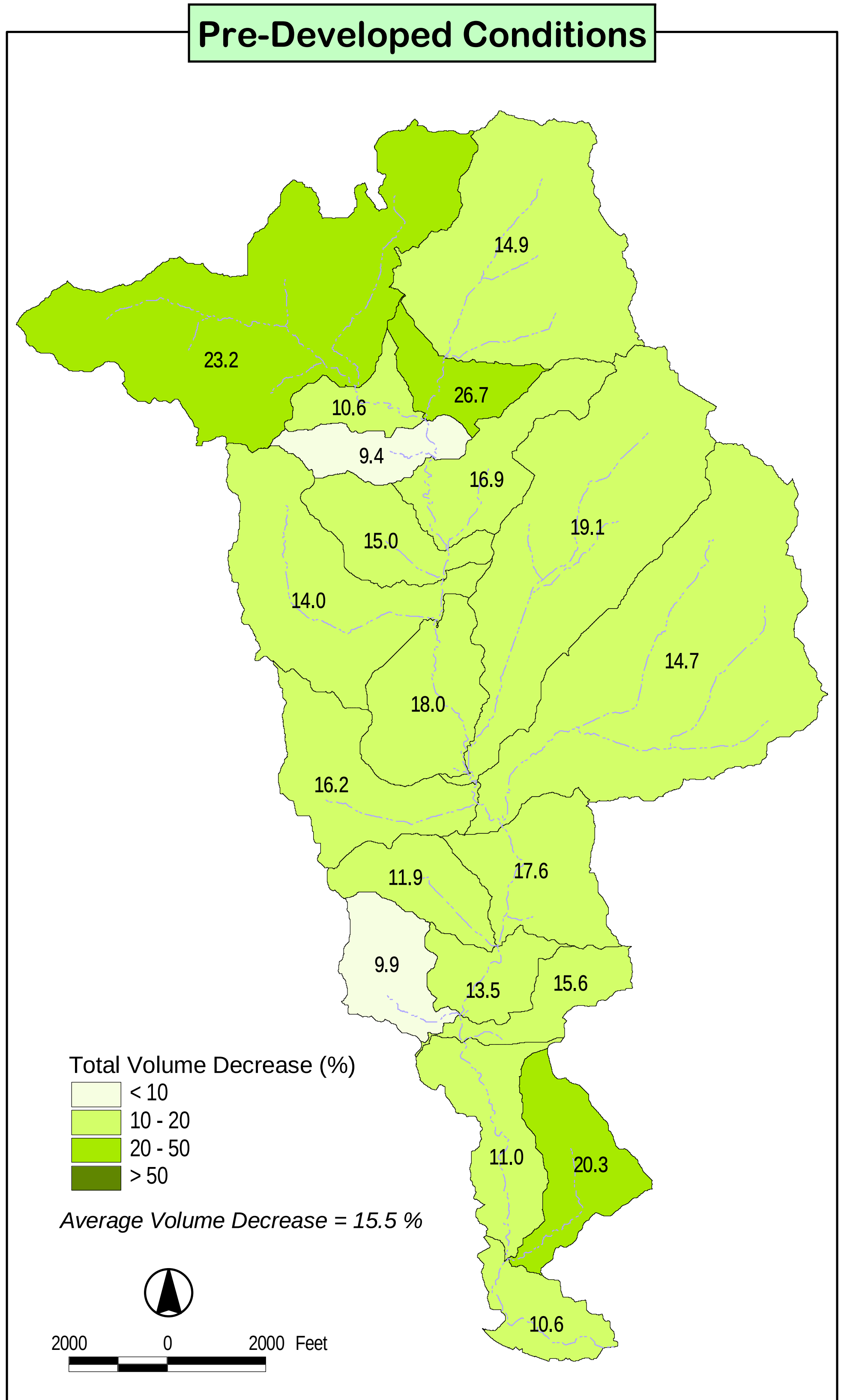
Total Volume Analysis - 10 Year Storm

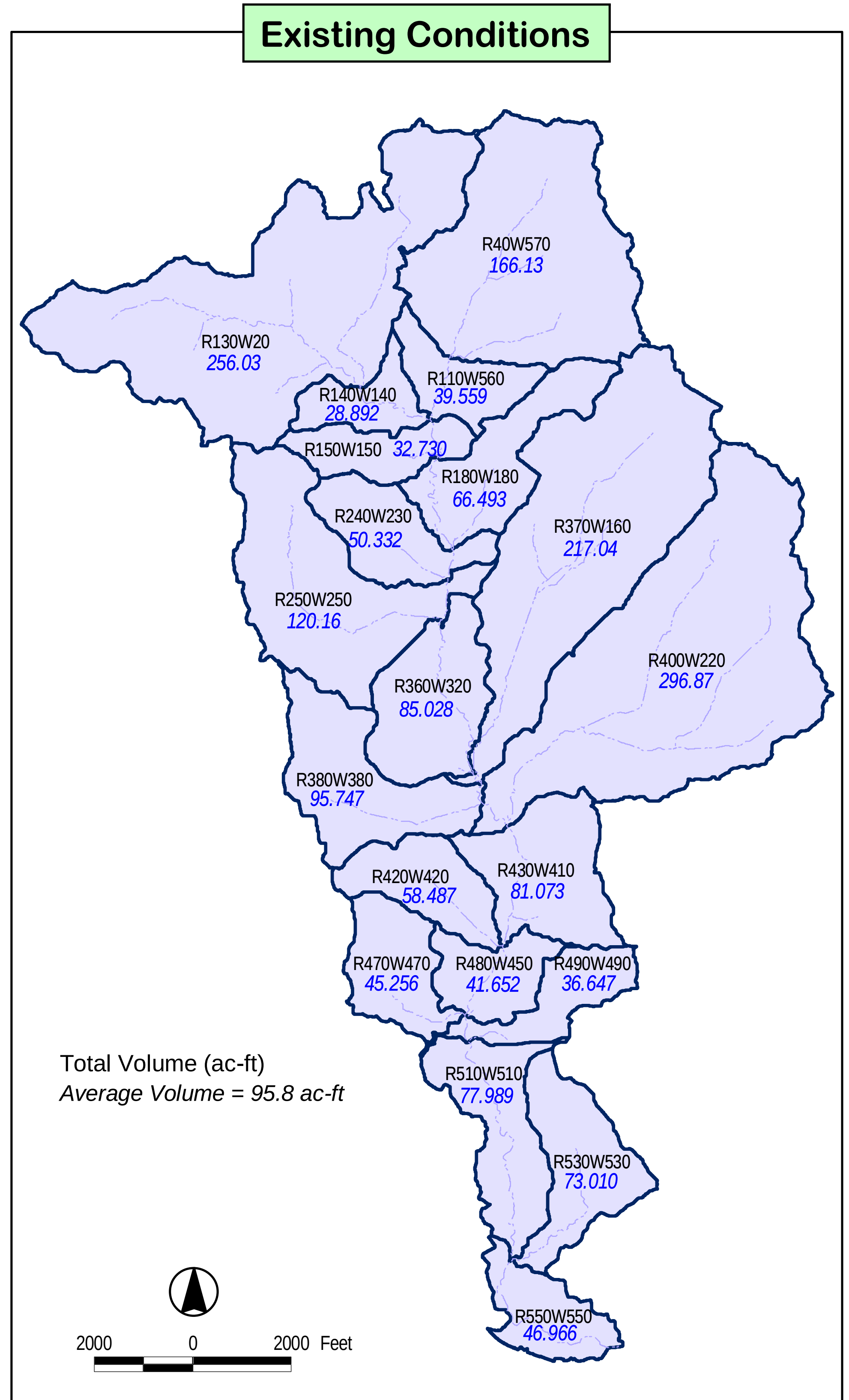


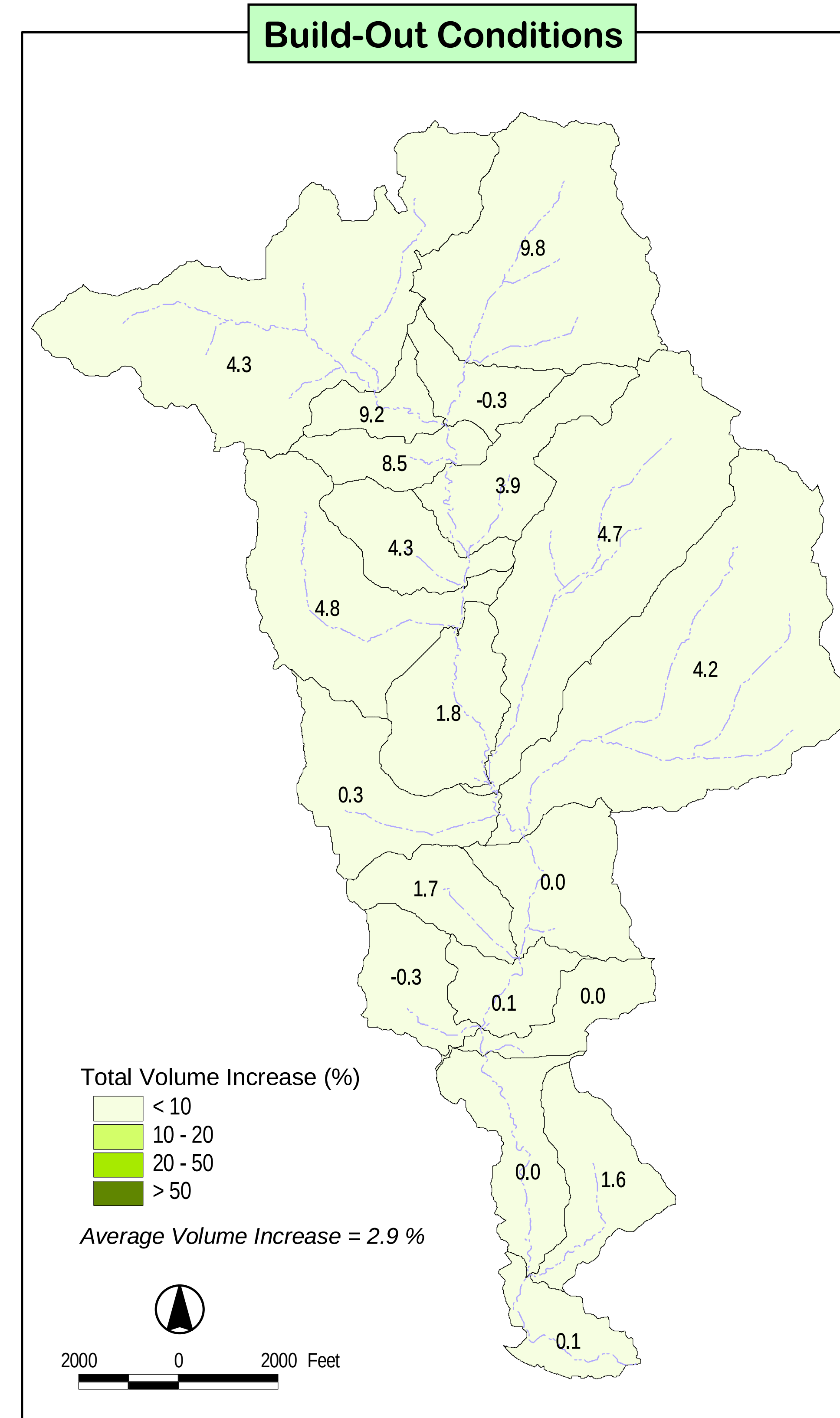
TRC Omni Environmental Corporation

Ramanessin Brook NPS Pollution Source Assessment and Stormwater Impact Study

Total Volume Analysis - 100 Year Storm





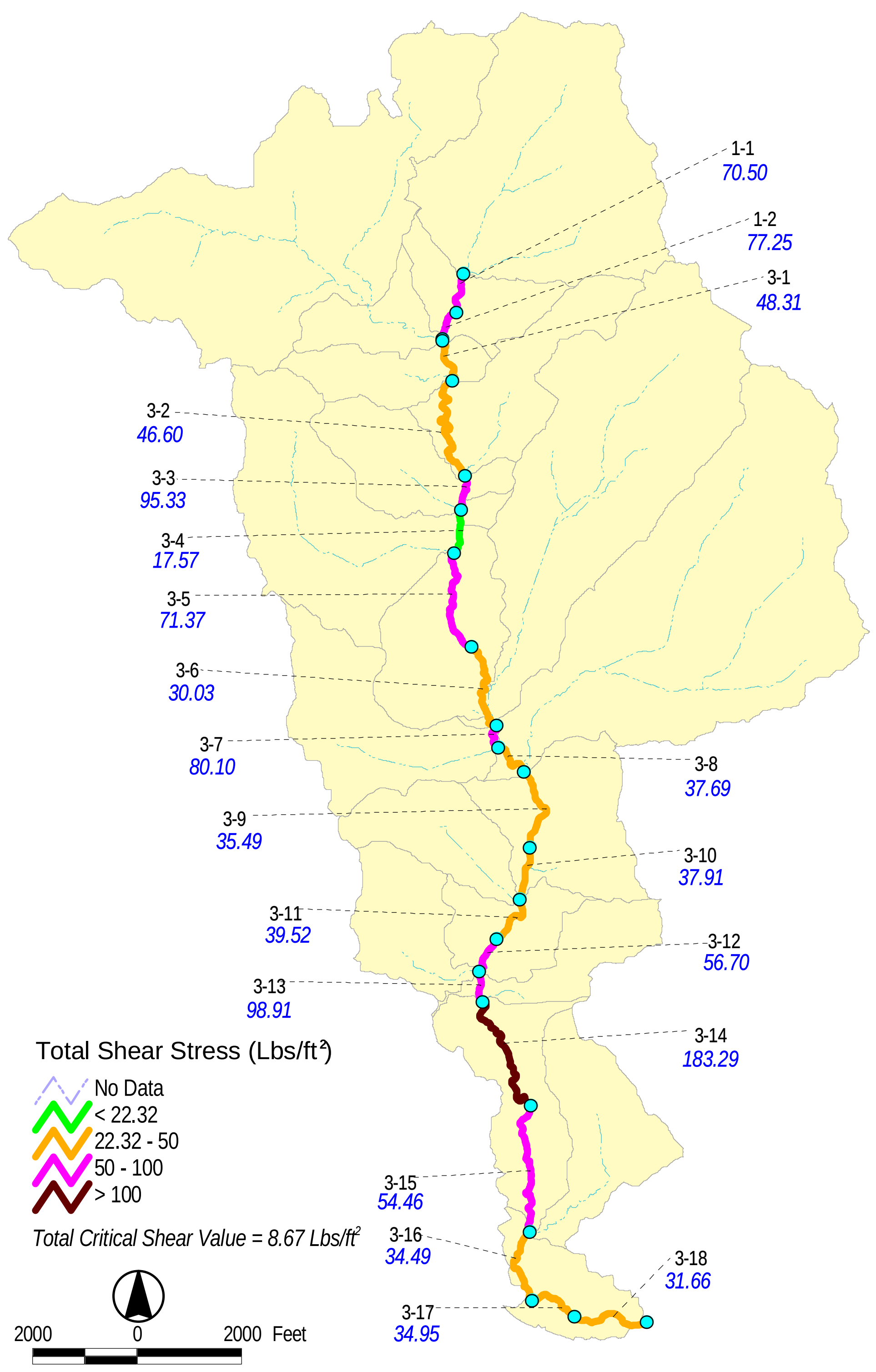


TRC Omni Environmental Corporation

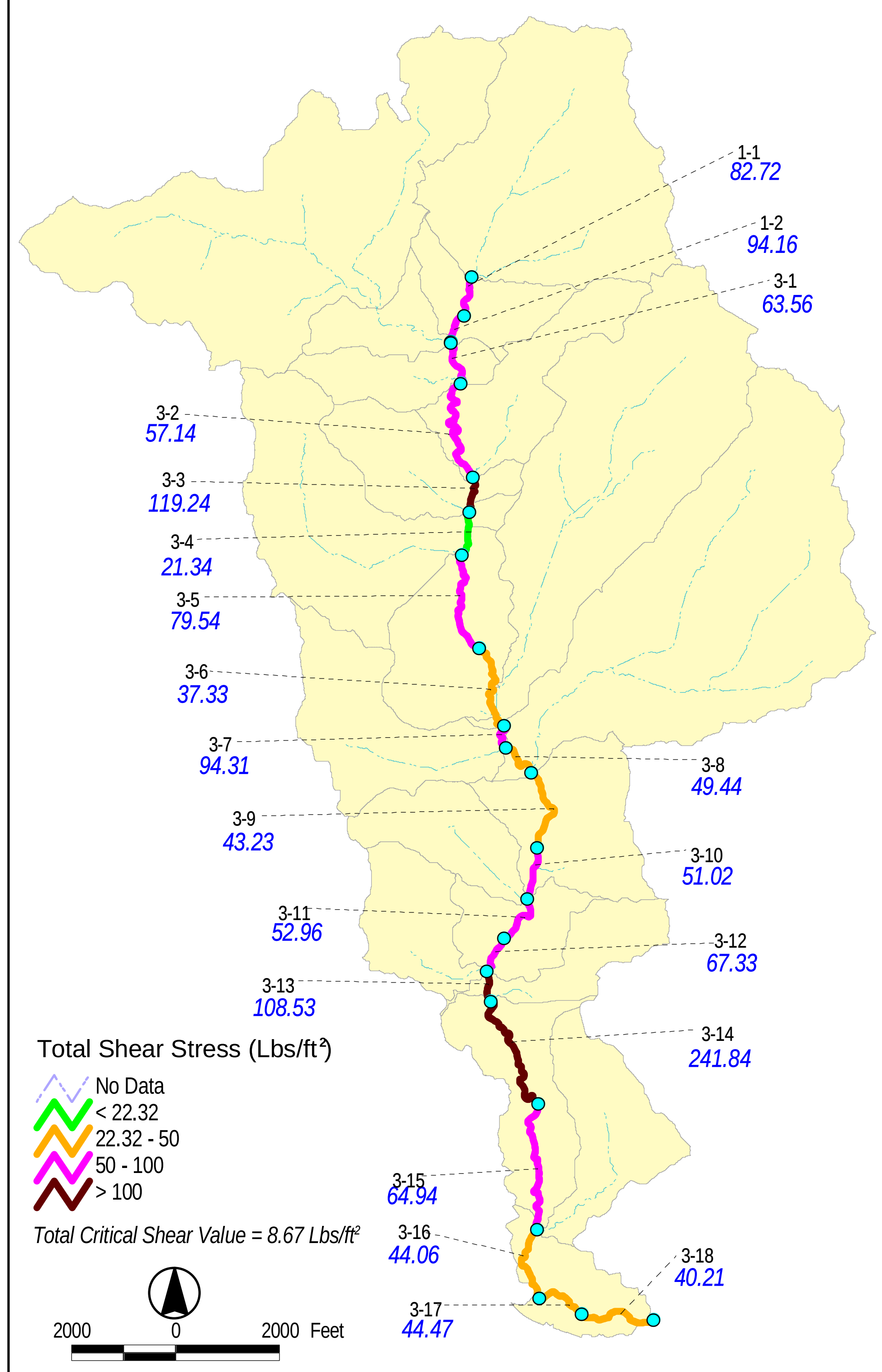
Ramanessin Brook NPS Pollution Source Assessment and Stormwater Impact Study

Total Shear Stress - 2 Year Storm

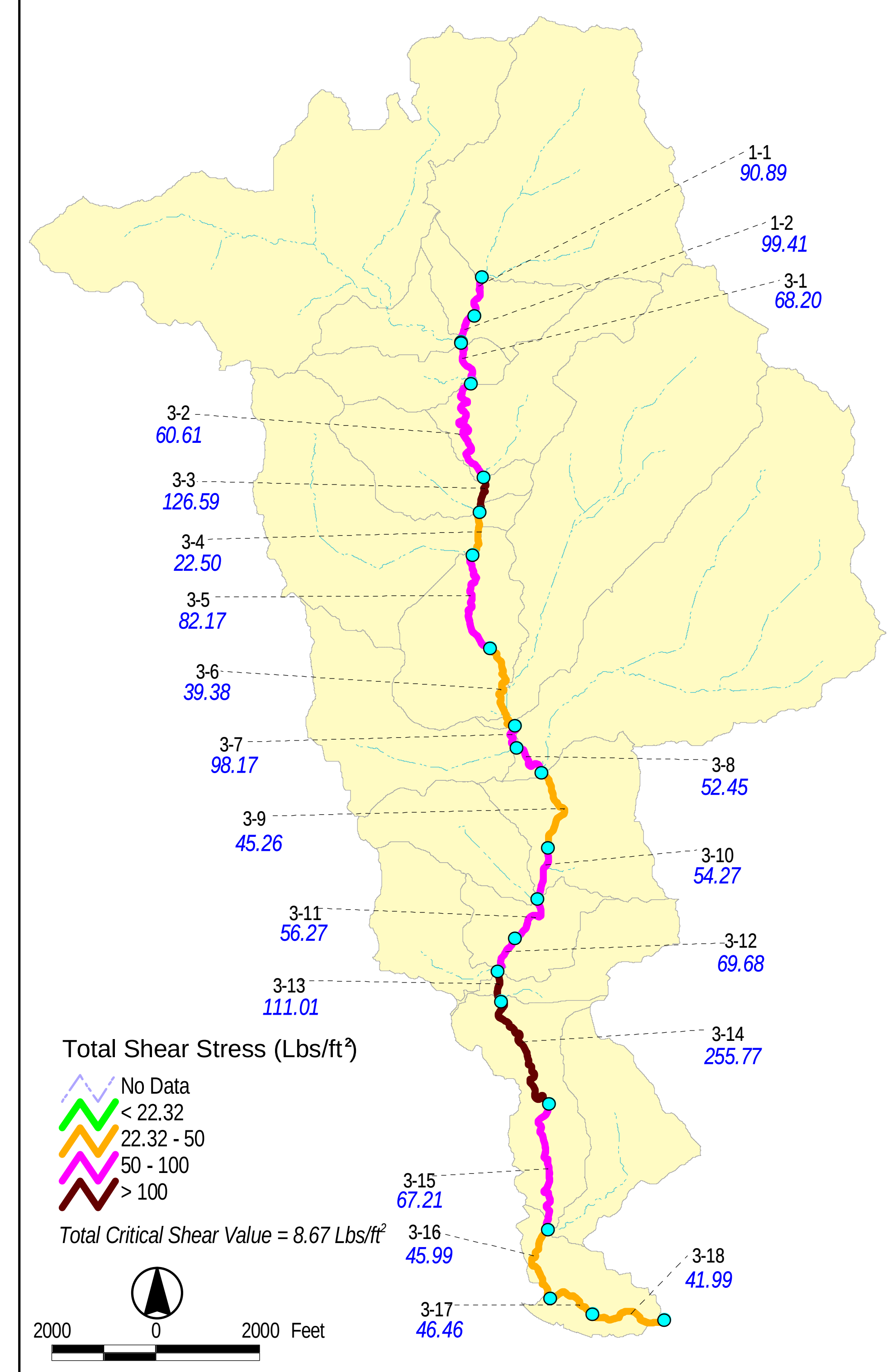
Pre-Developed Conditions



Existing Conditions



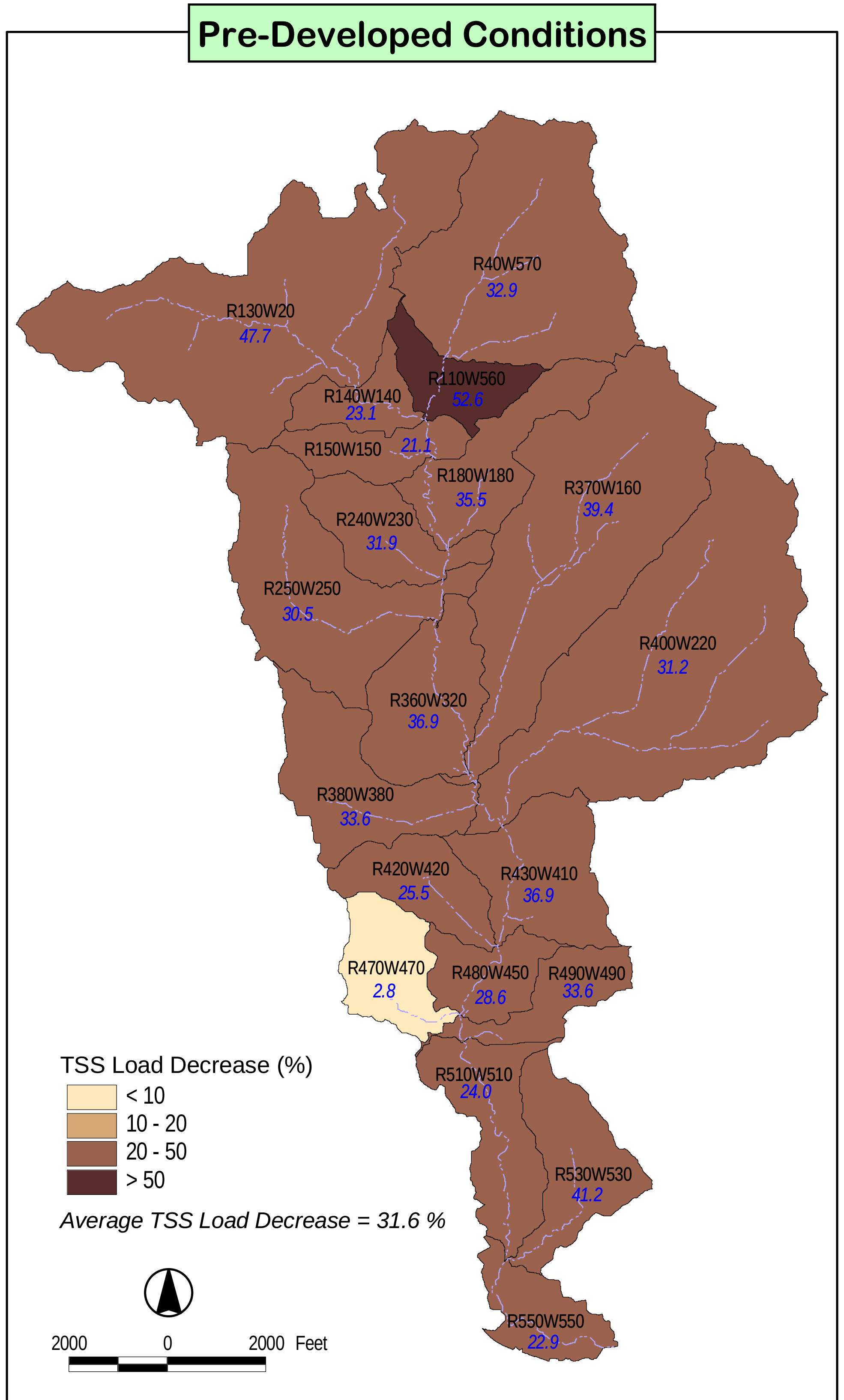
Build-Out Conditions

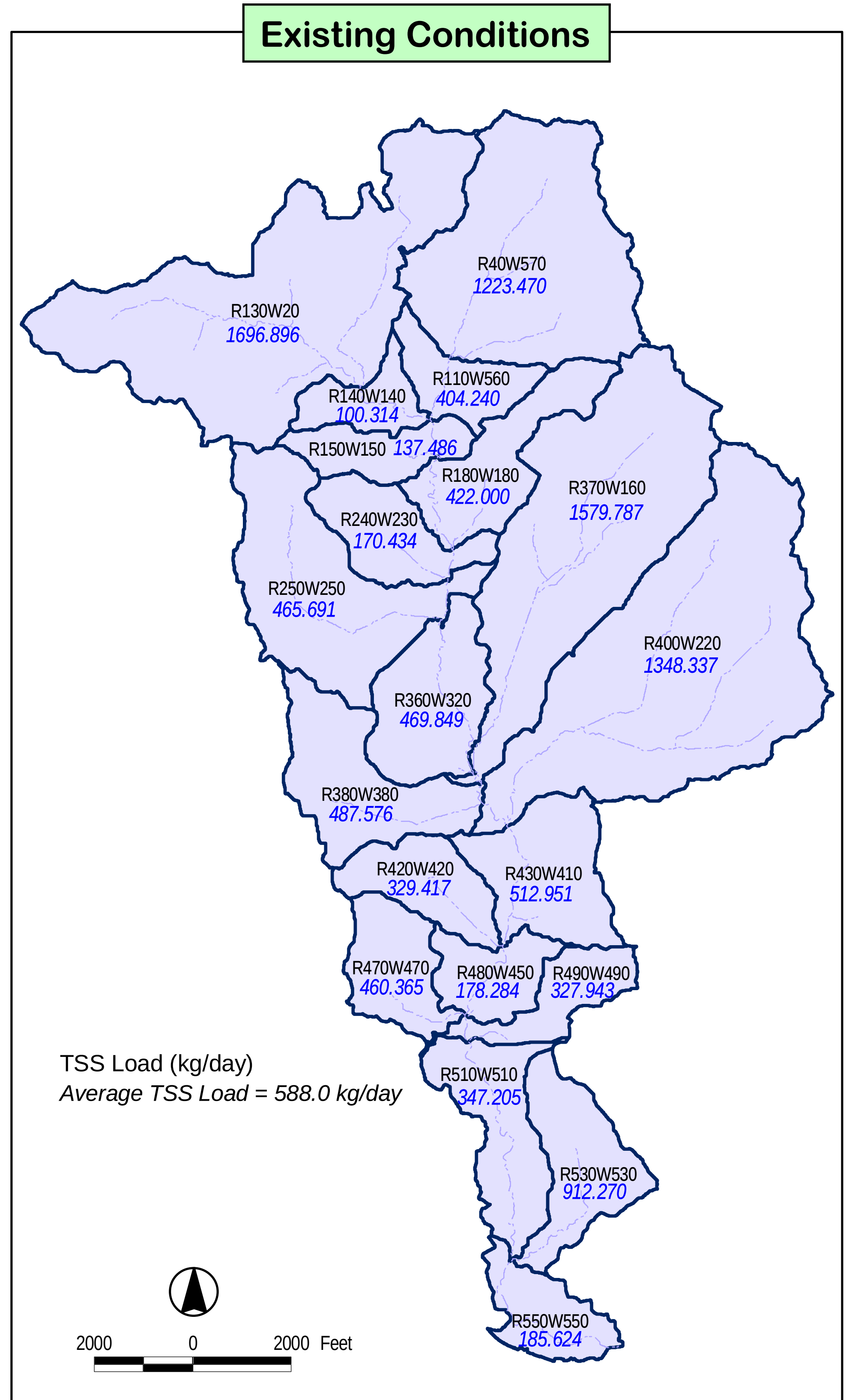


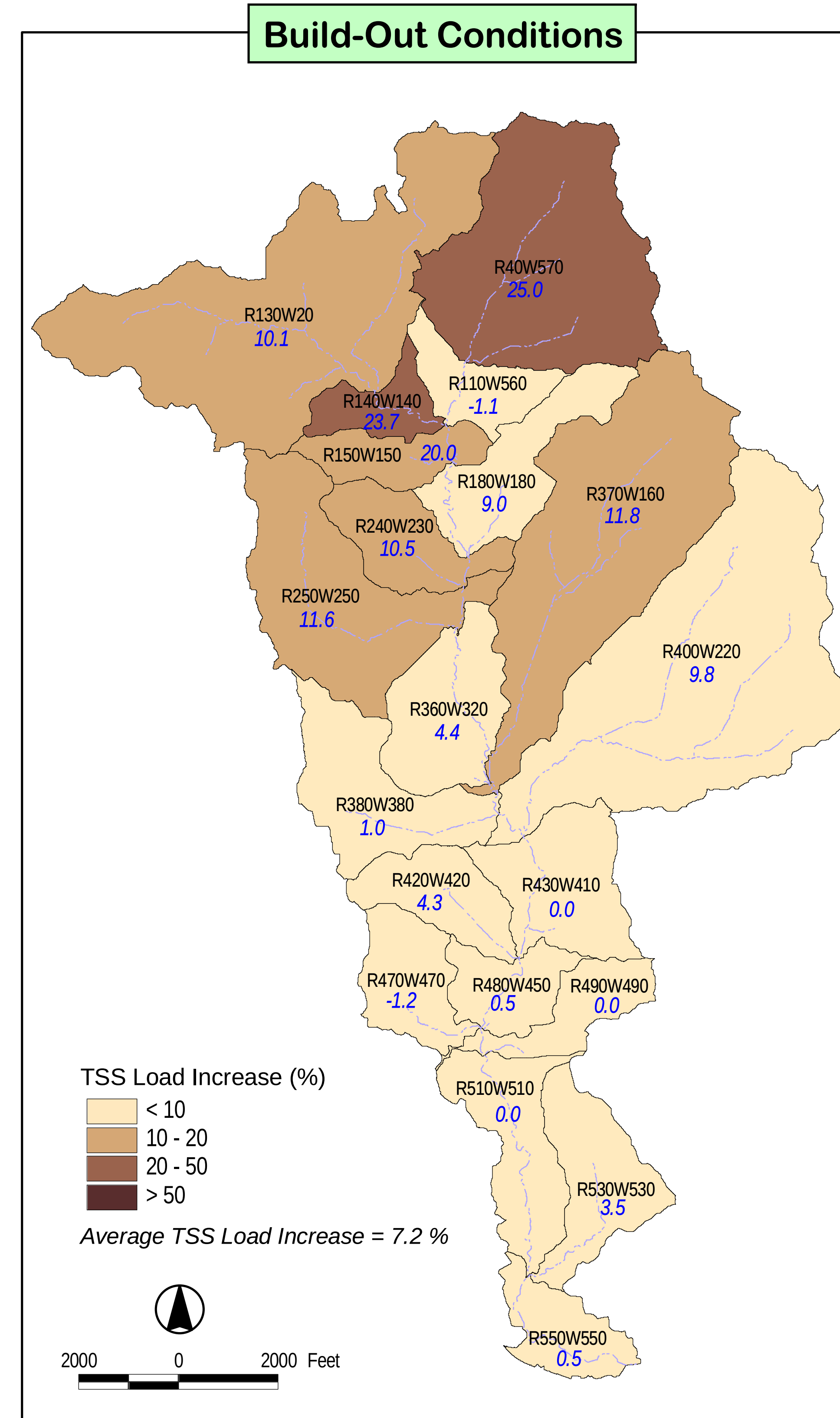
TRC Omni Environmental Corporation

Ramanessin Brook NPS Pollution Source Assessment and Stormwater Impact Study

Total Suspended Solids (TSS) Load - 2 Year Storm



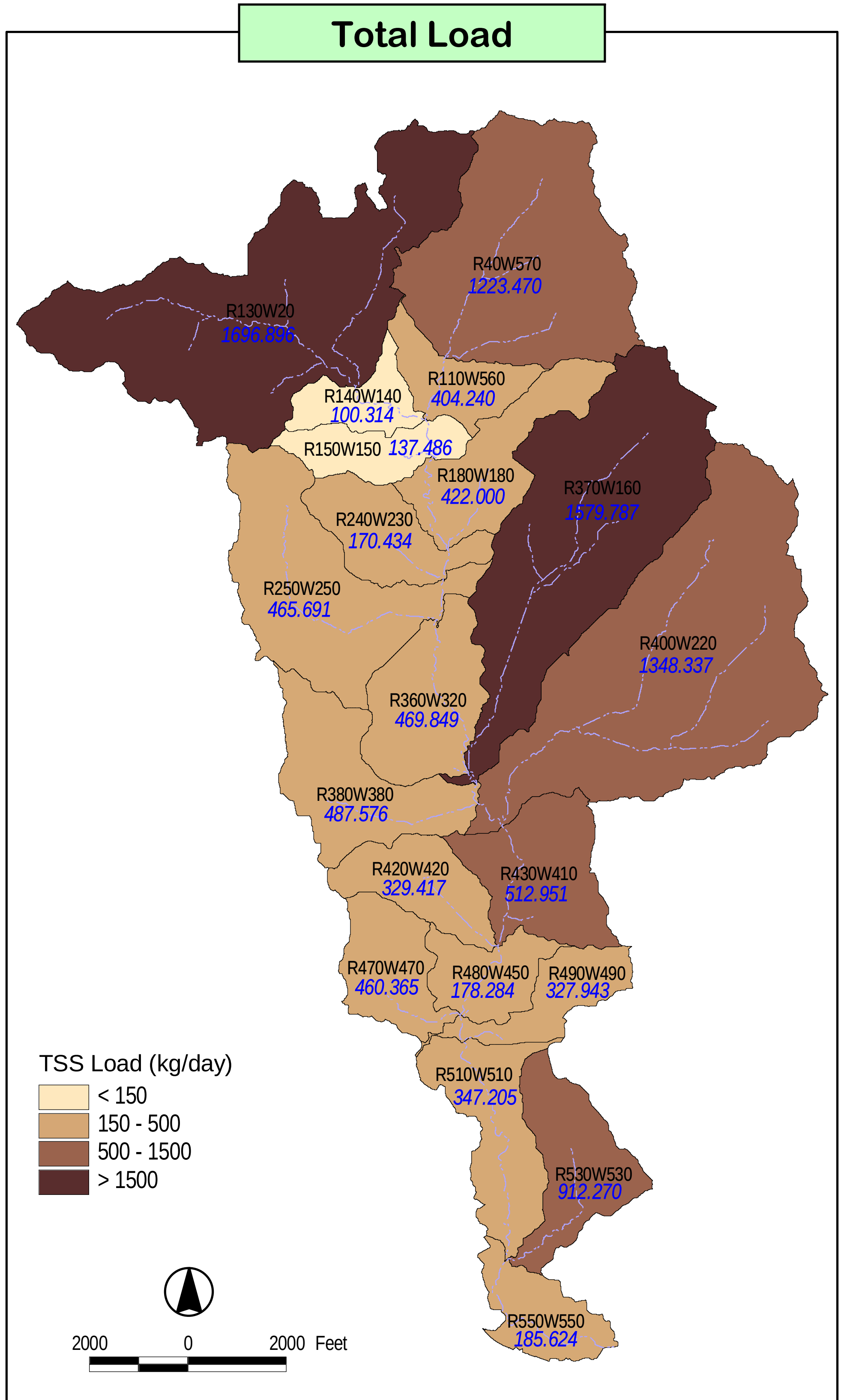


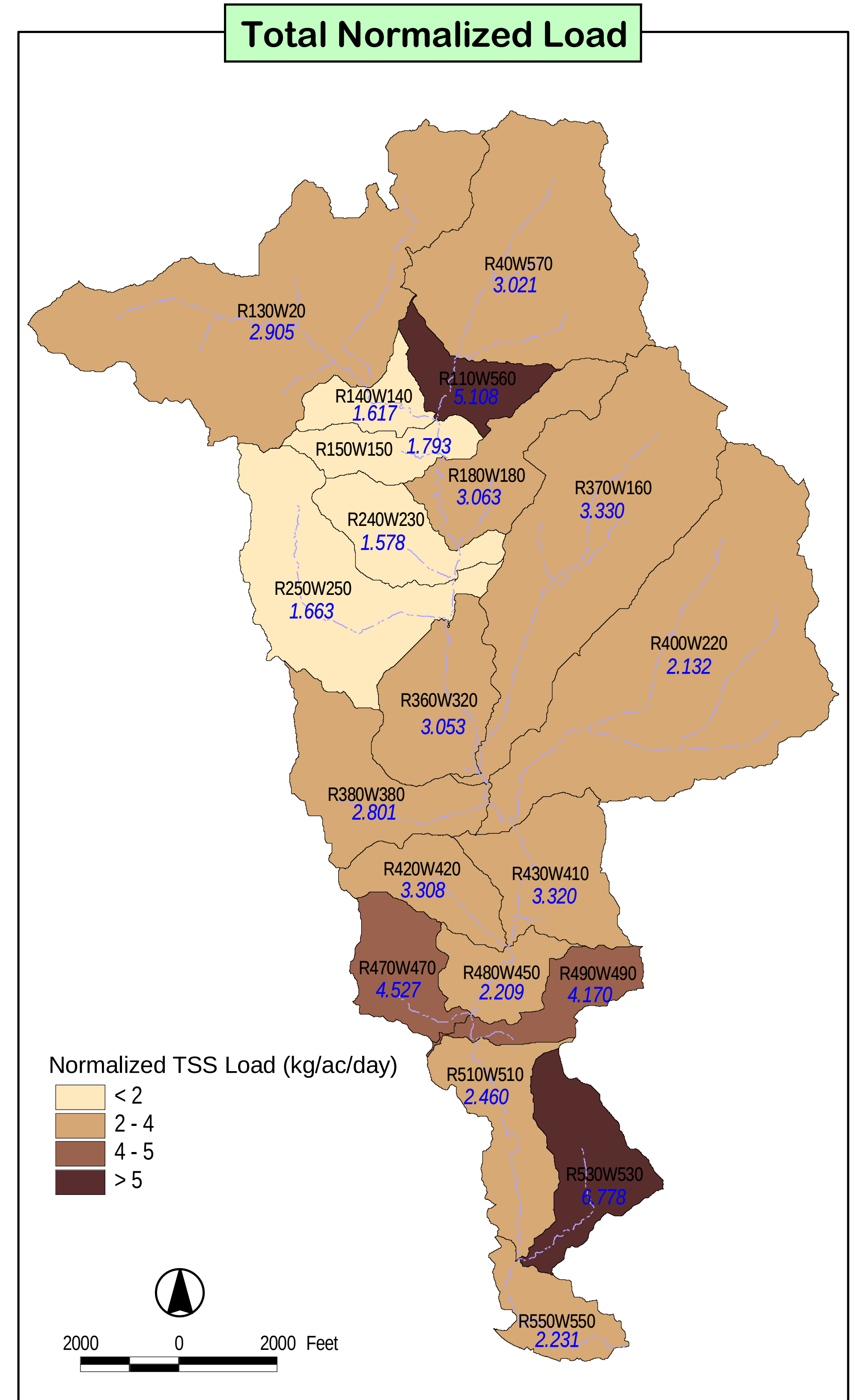


TRC Omni Environmental Corporation

Ramanessin Brook NPS Pollution Source Assessment and Stormwater Impact Study

Total Suspended Solids (TSS) Load - 2 Year Storm

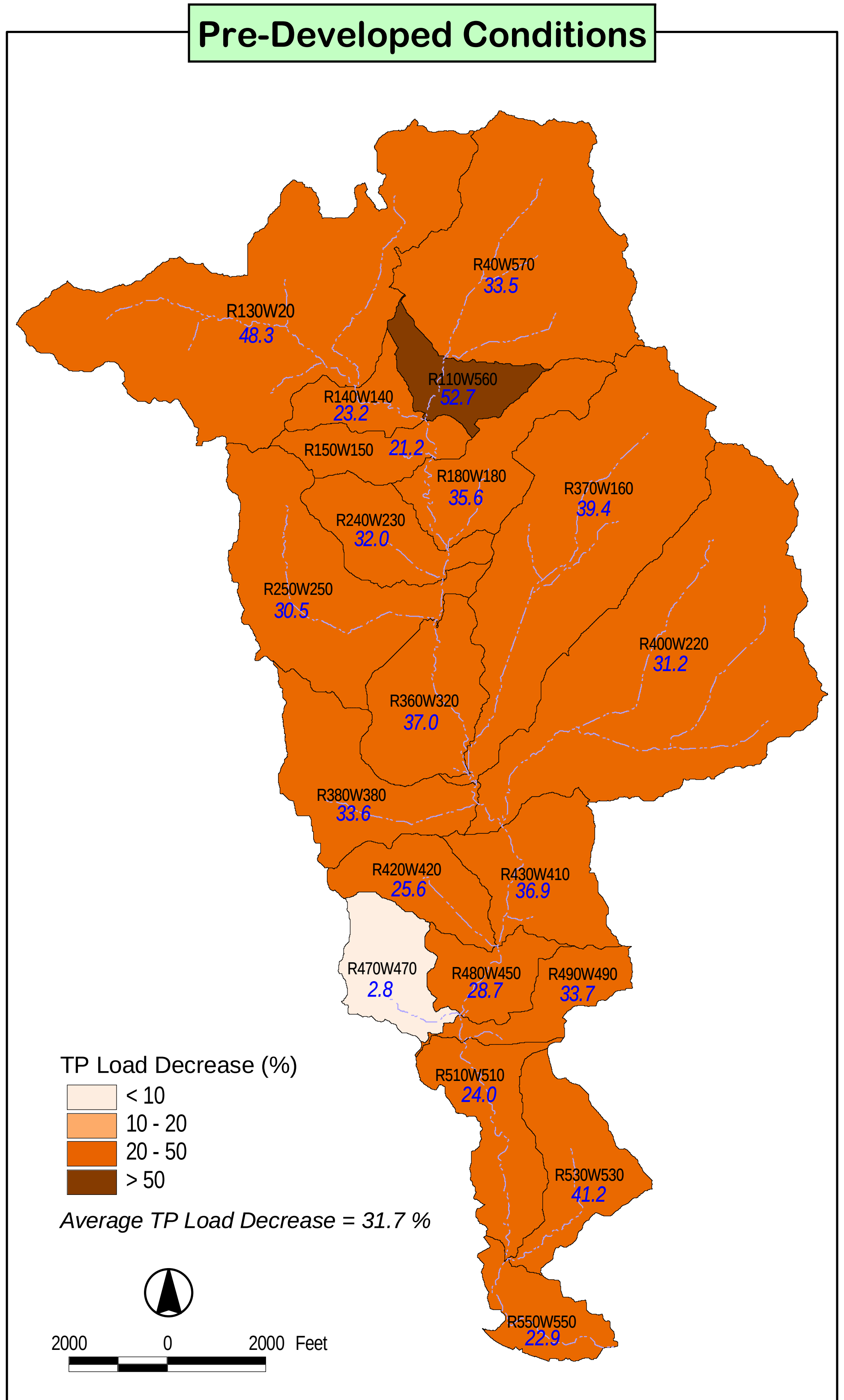


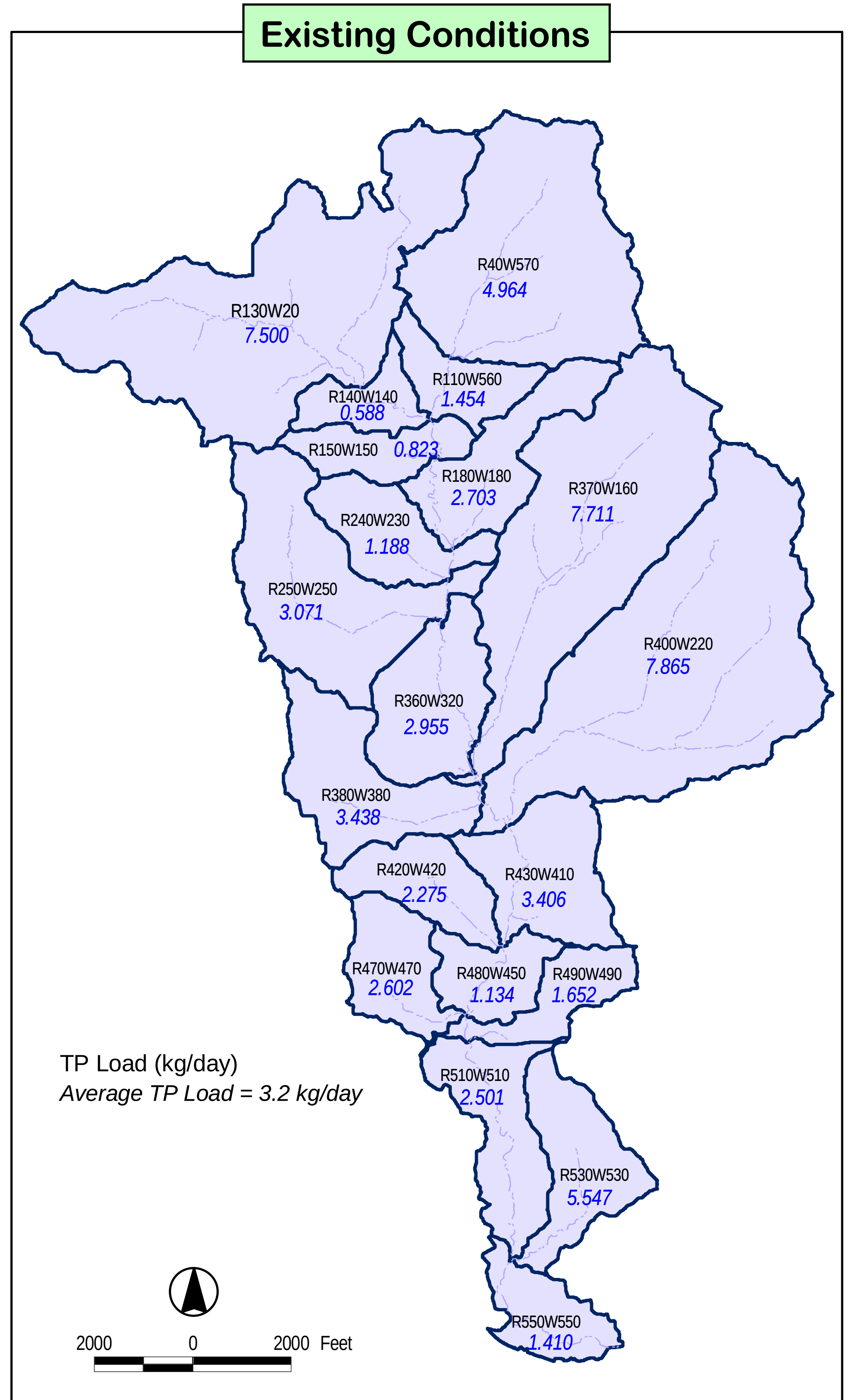


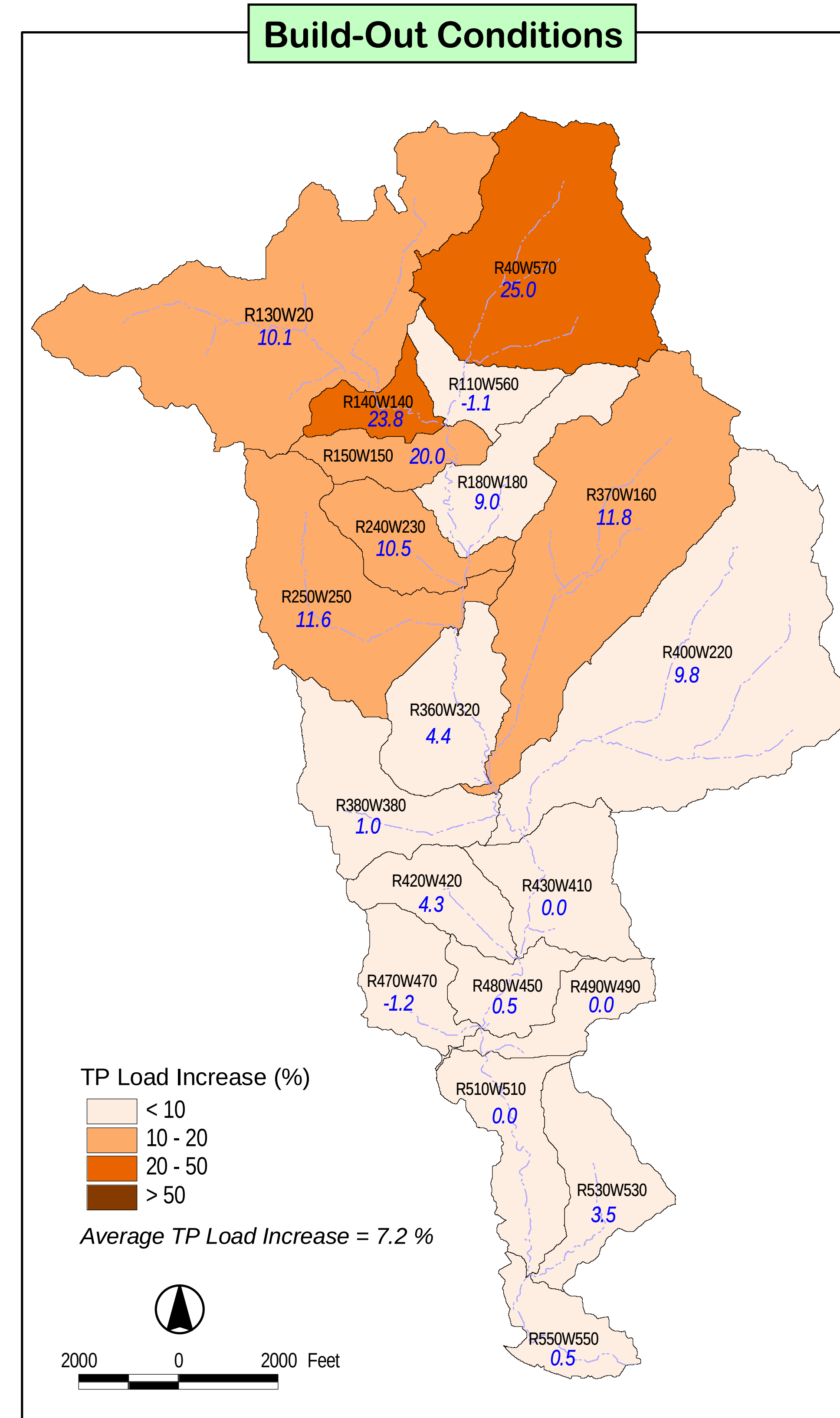
TRC Omni Environmental Corporation

Ramanessin Brook NPS Pollution Source Assessment and Stormwater Impact Study

Total Phosphorus (TP) Load - 2 Year Storm



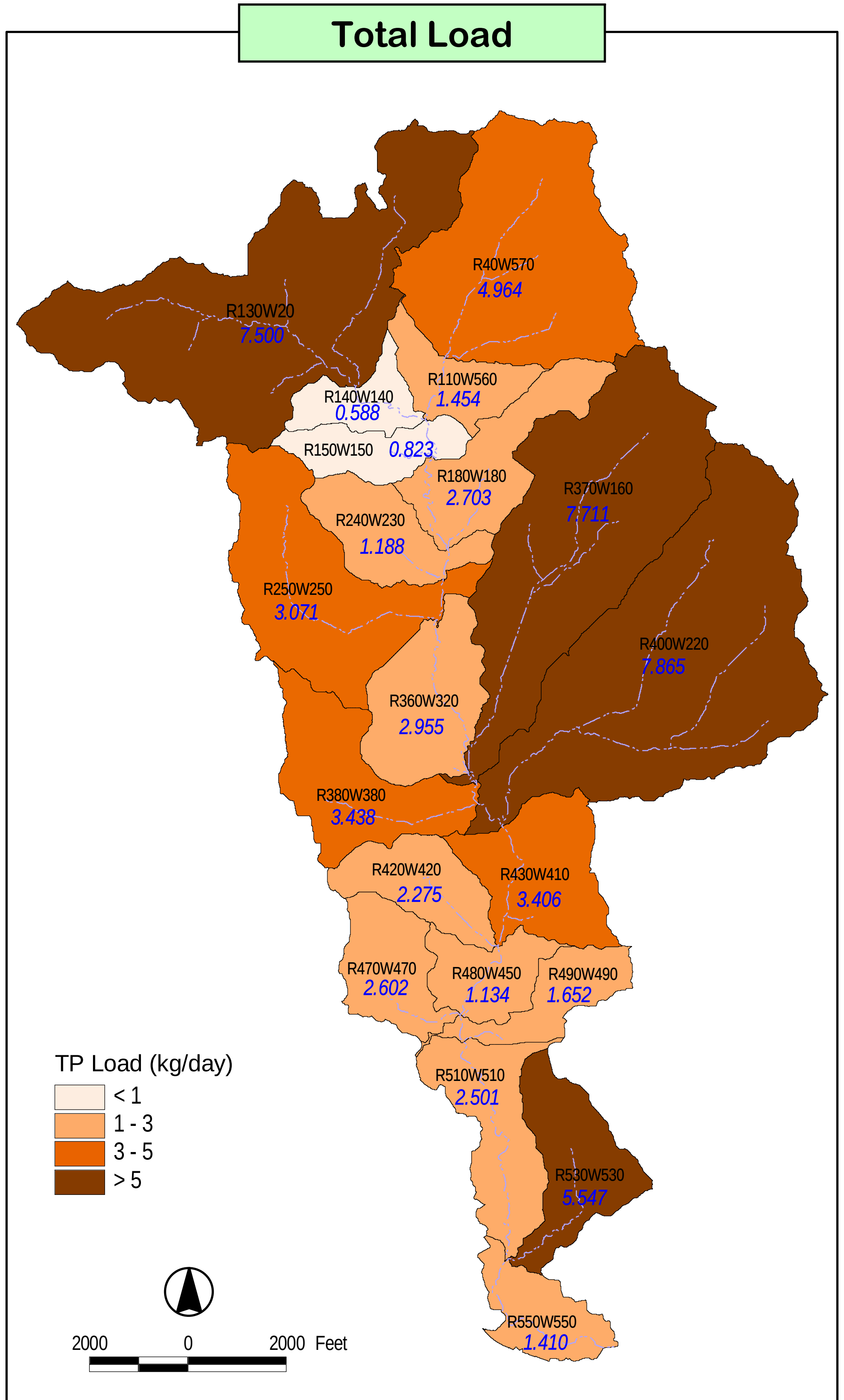


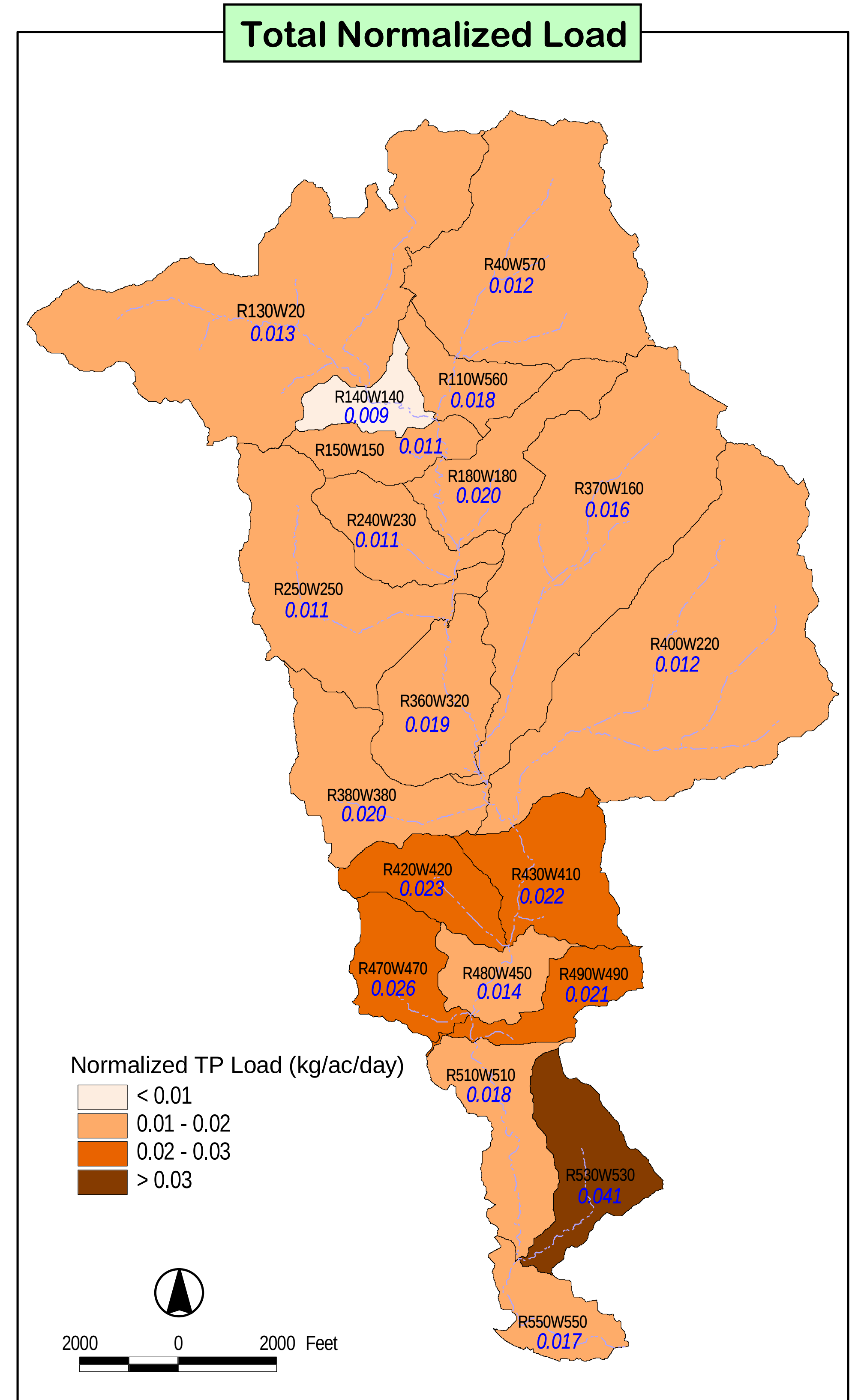


TRC Omni Environmental Corporation

Ramanessin Brook NPS Pollution Source Assessment and Stormwater Impact Study

Total Phosphorus (TP) Load - 2 Year Storm



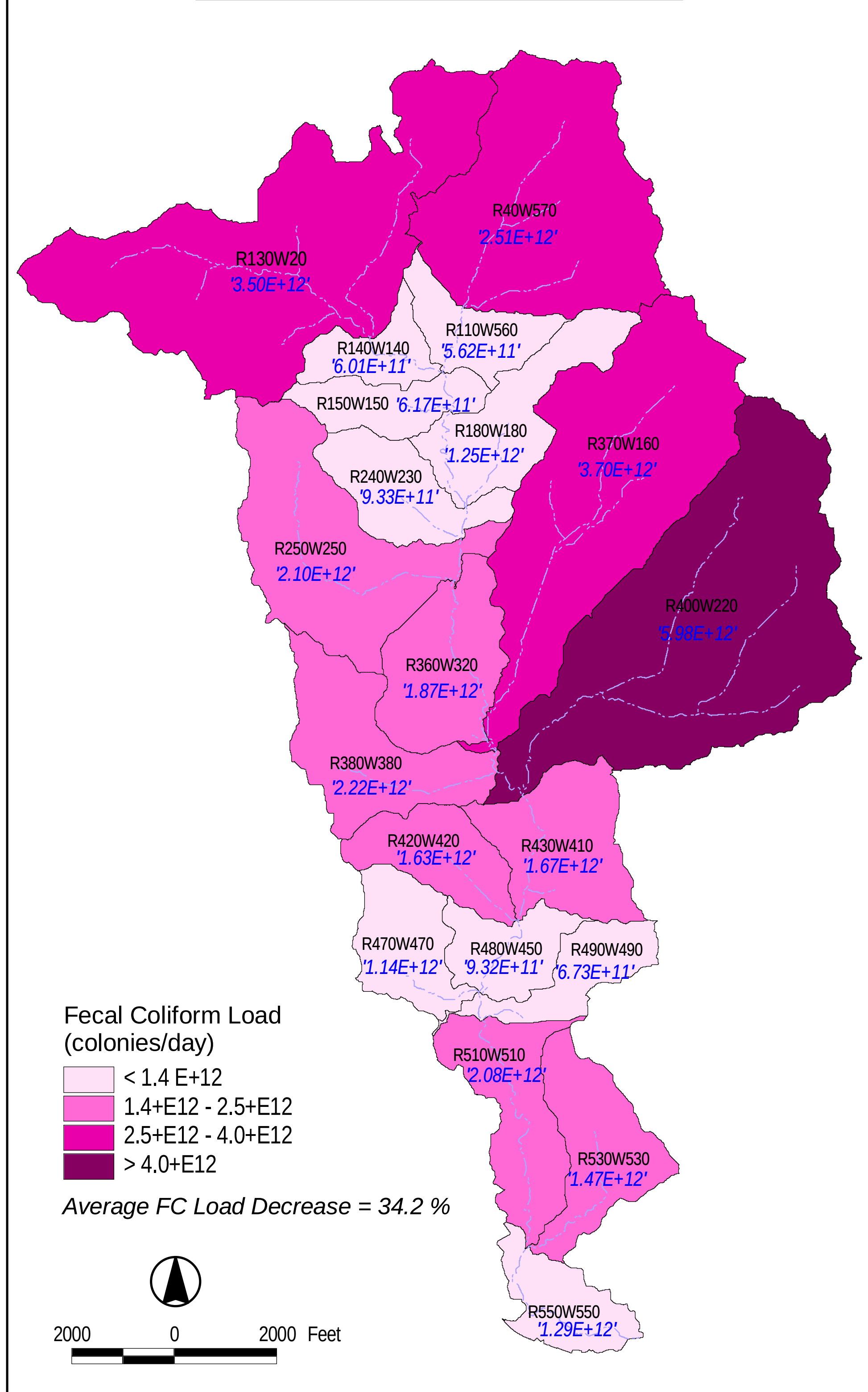


TRC Omni Environmental Corporation

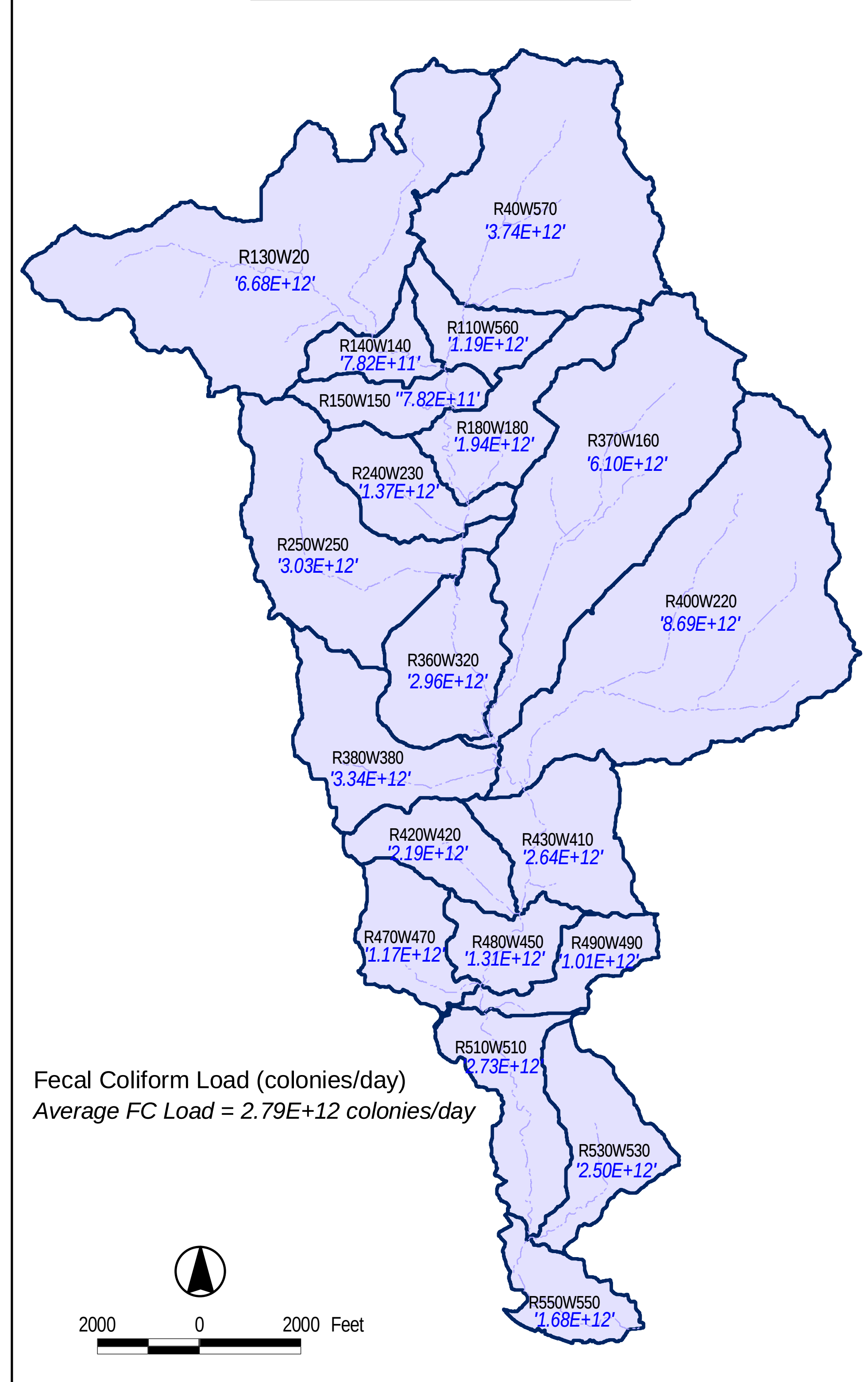
Ramanessin Brook NPS Pollution Source Assessment and Stormwater Impact Study

Fecal Coliform Load - 2 Year Storm

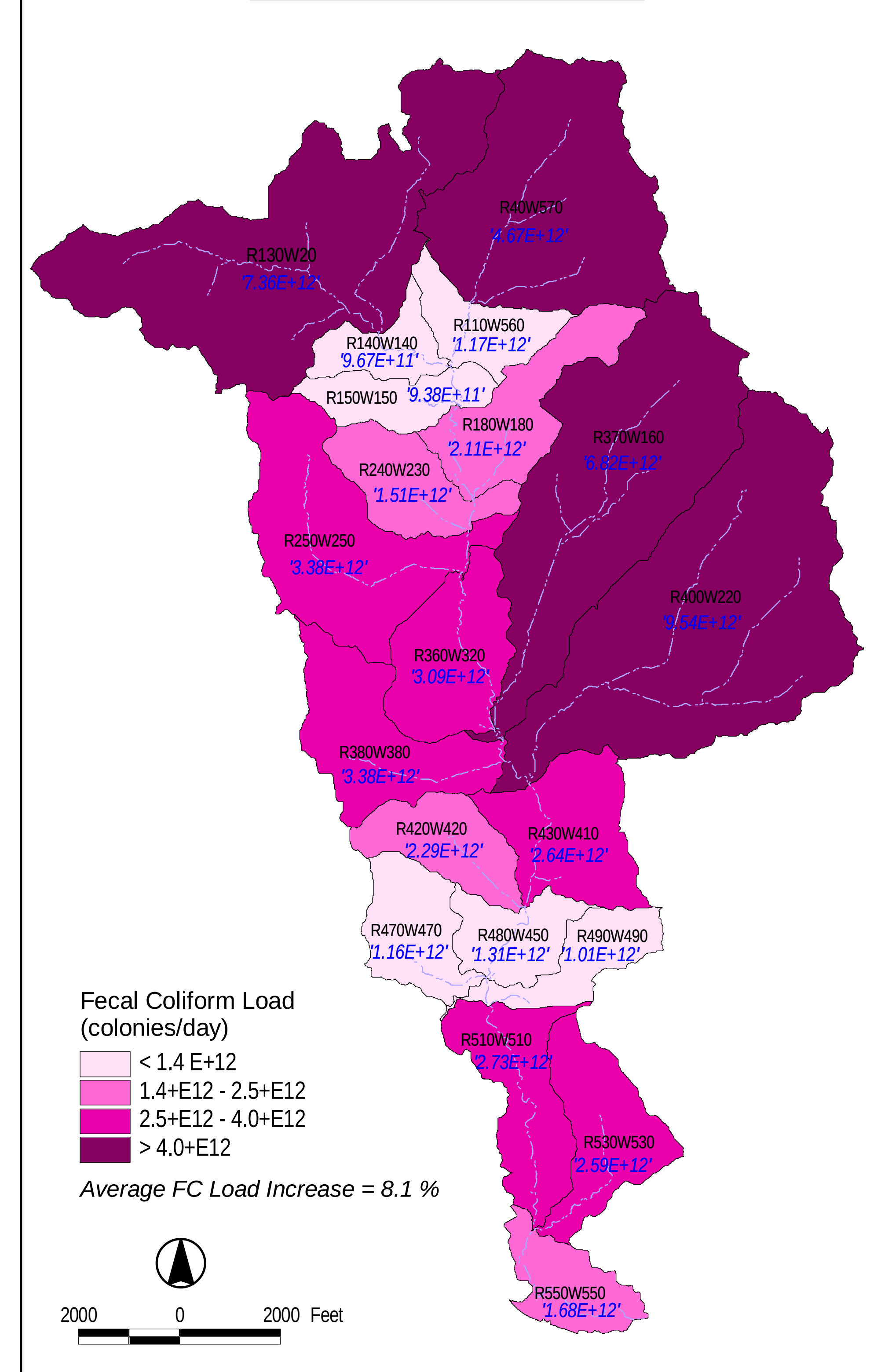
Pre-Developed Conditions



Existing Conditions



Build-Out Conditions



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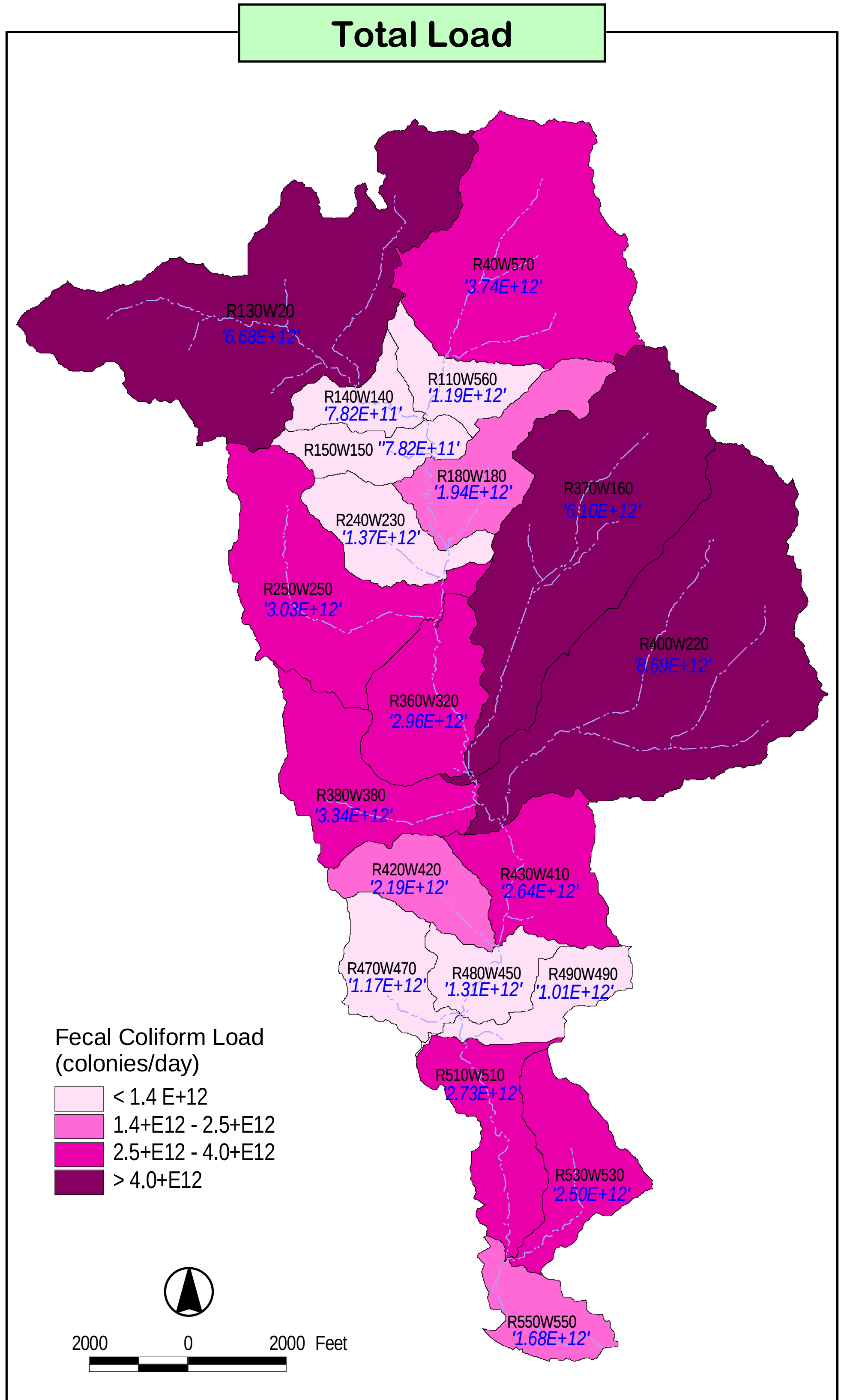
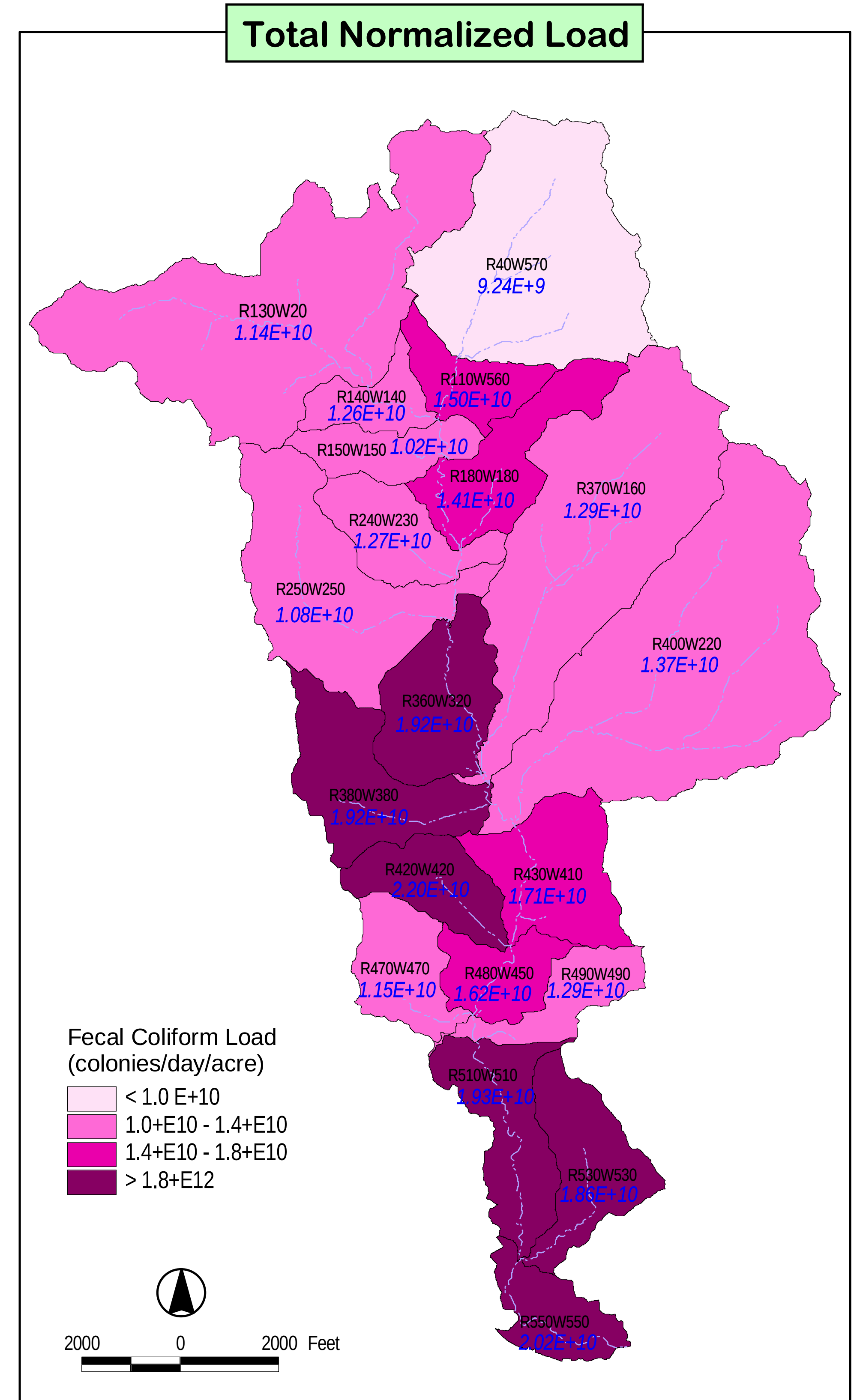
Fecal Coliform Load - 2 Year Storm





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APPENDIX G: Digital Data (CD)