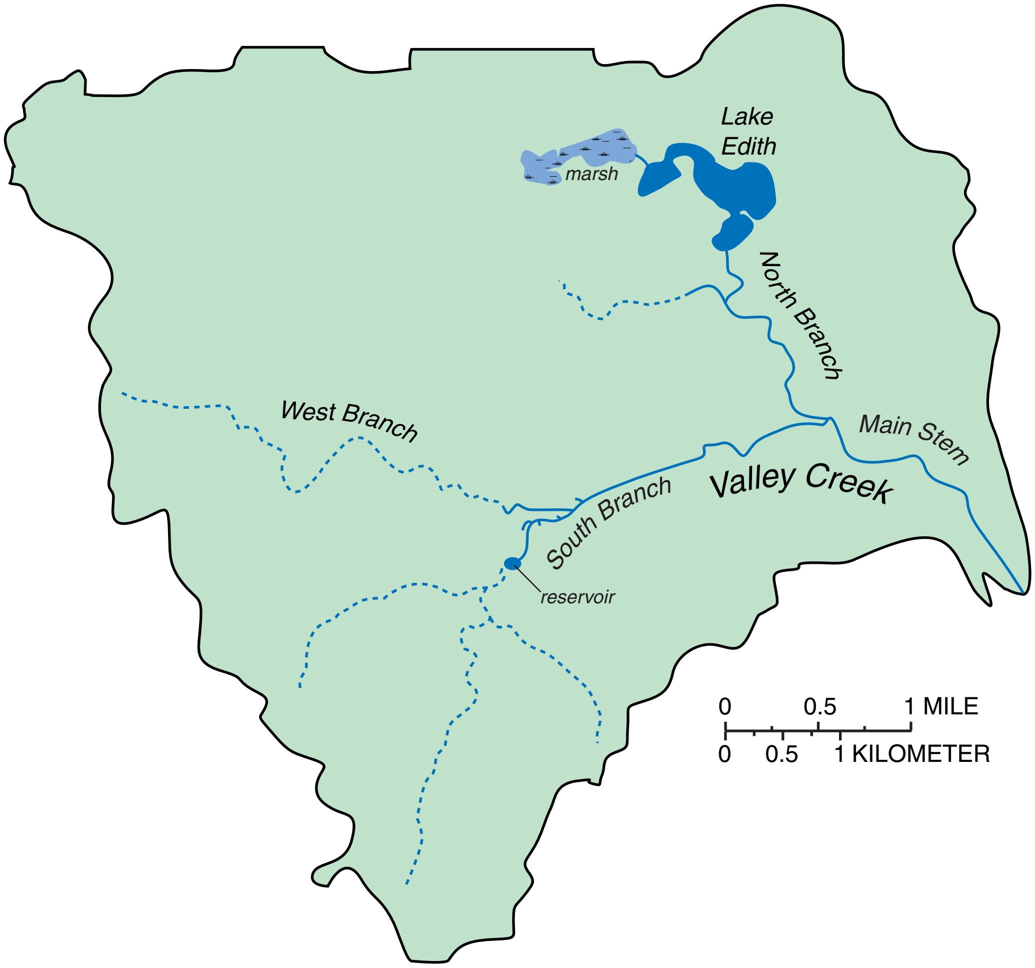
Monitoring and Modeling Valley Creek Watershed:
1. Executive Summary

Final Project Report
to the

LCMR

Legislative Commission on Minnesota Resources
30 June 1999



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St. Croix Watershed Research Station
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Watershed Science: Integrated Research and Education Program

Objective 1: Watershed Science in the Field

Monitoring and Modeling Valley Creek Watershed:

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FUNDING

Funding for this project approved by the Minnesota Legislature, ML 1997, Chapter 216, Sec. 15, Subd. 13(b) as recommended by the Legislative Commission on Minnesota Resources from the Minnesota Future Resources Fund.

COOPERATIONS AND ACKNOWLEDGMENTS

This project, Monitoring and Modeling Valley Creek Watershed, was Objective 1 of a larger project titled Watershed Science: Integrated Research and Education Program. Watershed Science was itself a collaboration among three parts of the Science Museum of Minnesota: the Our Minnesota Hall, Warner Nature Center, and the St. Croix Watershed Research Station. Pat Hamilton, director of the Our Minnesota Hall, was the overall project manager and was also in charge of Objective 2, Watershed Science in the Museum. Tom Anderson, director of Warner Nature Center, was in charge of Objective 3, Watershed Science Training. Scott Haire, as director of the high school students in Projects Club at the Museum, provided time and energy in helping to execute the project. Joel Halvorson of the Our Minnesota Hall set up the Museum s Map Lab and provided helpful data and facilities.

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Private Citizens

The following citizens kindly allowed access to Valley Creek through their property:

Ms. Bette Barnett
Ms. Marnie Becker
Mr. & Mrs. Scott Blasko
Dr. & Mrs. John Doyle
Ms. Donna Hanson
Mr. & Mrs. John Hornickel
Ms. Kristi Kreischer
Mr. Raymond Lindeman
Mr. & Mrs. Randy Meier
Mrs. Evelyn Meissner
Ms. Alida Messinger
Mr. & Mrs. Arnie Milano
Ms. Winifred Netherly
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Mr. & Mrs. Gary Ridenhower
Mr. Steve Rosenmeier
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Mr. & Mrs. Mike Snyder

COOPERATIONS AND ACKNOWLEDGMENTS
(continued)

Government Agencies

City of Afton
Legislative Commission on Minnesota Resources
Metropolitan Council Environmental Services
Minnesota Dept. of Agriculture
Minnesota Dept. of Health
Minnesota Dept. of Natural Resources
Minnesota Pollution Control Agency
U.S. Dept. of Agriculture ARS
U.S. Geological Survey
Valley Branch Watershed District
Washington County
Washington County Soil and Water Conservation District

Educational and Private Institutions

Bell Museum of Natural History
Belwin Foundation
St. Paul Public Schools
Stillwater Area High School
University of St. Thomas

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Mr. Andy Weaver (SAHS)

Abbreviations: LSP, Land Stewardship Project; MCES, Metropolitan Council Environmental Services; MDNR, Minnesota Department of Natural Resources; MPCA, Minnesota Pollution Control Agency; SAHS, Stillwater Area High School; Wash. Cty., Washington County; WI-DNR, Wisconsin Department of Natural Resources.

REPORTS

1. **Executive Summary**
2. **Methods of Hydrologic Data Collection**
3. **Surface-Water Hydrology**
4. **Atlas of Physiography, Hydrology, and Land Use**
5. **Groundwater Hydrology and Flow Model**
6. **Modeling the Effects of Urbanization on Surface Flows and Water Quality in the Valley Branch Watershed**

DATA ON CD-ROM

¥ Spatial Data for Valley Creek Watershed
¥ Hydrologic Data for Valley Creek, 1997-98

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Monitoring and Modeling Valley Creek Watershed:

1. Executive Summary

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PROJECT ABSTRACT

Trout streams are sensitive to urbanization, which can alter the watershed hydrology by increasing runoff from impervious surfaces, thereby increasing summer water temperatures and inputs of sediment, nutrients, and other contaminants. Valley Creek is a healthy trout stream in southeastern Washington County that is facing potential urbanization in the coming decade. The purpose of this project was primarily (1) to document baseline conditions in Valley Creek and its watershed prior to such urbanization to provide a reference against which future changes may be measured, and (2) to model the surficial watershed and the groundwater flow to gain insight on how the watershed functions hydrologically and to test how different patterns of urbanization could alter the hydrology of Valley Creek. The scope is limited primarily to hydrologic data collected during 1997—98, and the spatial data is current as of about 1995. This executive summary synthesizes the five other reports that were produced by this project: methods of hydrologic data collection, surface-water hydrology, spatial data compilation, groundwater hydrology, and surficial watershed model.

Methods of *Hydrologic Data Collection* documents sampling procedures and the establishment of five automated stream-monitoring stations in the watershed. Each station measured stream stage, temperature, and specific conductance; discharge was estimated by using empirical stage-discharge relationships. Samples were analyzed primarily for suspended solids and nutrients; a few selected samples were analyzed for major ions as well. The primary findings of the report *Surface-Water Hydrology* were that baseflow in Valley Creek was large enough to indicate contributions of groundwater from beyond the watershed boundary, and that some important water-quality variables were very different between the two main branches of the creek. The South Branch, fed by groundwater, had a stable temperature regime within the range favored by trout, but a

relatively high total nitrogen content caused by discharge of nitrate-contaminated groundwater. In contrast, the North Branch, fed by outflow from Lake Edith, had wide seasonal temperature changes that exceeded the range favored by trout about 22% of the time in 1998. The *Atlas of Physiography, Hydrology, and Land Use* compiles spatial data pertaining to the physical and cultural characteristics of the Valley Creek watershed, most of which are displayed as thematic maps and supported by discussion of their relationships. Physical themes include surface geology, bedrock geology, hydrology, soils, and vegetation; cultural themes include land use, settlement, existing public policy toward development, and alternative scenarios of possible urbanization patterns. These themes provided input data for modeling the watershed hydrology. The report *Groundwater Hydrology and Flow Model* confirmed the strong influence of groundwater on South Branch Valley Creek and concluded that the likely source of this groundwater was the Prairie-du-Chien/Jordan (PdC/J) aquifer. The groundwatershed for this aquifer, that is, the area of aquifer that could contribute groundwater to Valley Creek, was determined from maps of potentiometric surfaces to be about 60—80 km^2, substantially larger than the surficial watershed (about 45 km^2). An analytic-element groundwater-flow model constructed with the program MLAEM reproduced this groundwatershed and indicated that groundwater travel times (the time it takes groundwater to reach the creek) were about 30—40 years over most of the groundwatershed. The report *Modeling the Effects of Urbanization on Surface Flows and Water Quality in the Valley Branch Watershed* documents the application of two modeling programs, the Soil and Water Assessment Tool (SWAT) and the Water and Erosion Prediction Project (WEPP) to the Valley Creek watershed. WEPP proved superior in sensitivity to land-use parameters and in simulation of hillslope processes; consequently WEPP was used to simulate the hydrologic impacts of different urbanization scenarios. Runoff was predicted to increase under the high-density development scenario because of the increased area of impervious surfaces and their linkages via curbs and gutters. In contrast, the model predicted that lower density development without curb and gutters would decrease runoff compared to present land use because of the conversion of agricultural land to grassland. The model predicted a decrease in sediment yield for all urbanization scenarios because of the conversion of agricultural land to impervious surfaces or perennially vegetated grassland, each with low erosion rates, combined with the effectiveness of storm-water detention ponds to trap sediment. However, channel erosion was not evaluated in the model.

In aggregate these reports confirm that Valley Creek has thus far remained a high-quality stream, with the possible exception of the high total nitrogen content of the South Branch. Erosion should be particularly guarded against in this branch because of the potential of particle-bound phosphorus to spur over-abundant growth of aquatic vegetation, and because of the detrimental effect of siltation on trout habitat. Recharge in the groundwatershed of Valley Creek should be protected to maintain large baseflows in the creek. Because the groundwatershed extends into already rapidly-urbanizing areas, practices that maximize infiltration and minimize stormwater runoff should be encouraged. Finally, increased runoff from high-density development should be avoided, as this runoff could increase stream temperatures beyond the range tolerated by trout and other desired species.

INTRODUCTION

Importance

Valley Creek, variously called Valley Branch Creek (VBWD, 1995), Valley Branch (USGS, 1967), or previously Bolles Creek (Winchell, 1888), in southeastern Washington County near the historic village of Afton is generally regarded as the finest trout stream in the Minneapolis-St. Paul metropolitan area (Figure 1). All three species of stream trout (brown, rainbow, and native brook) reproduce successfully in the creek (Waters, 1983). The stream also harbors the American brook lamprey, a relatively rare, non-parasitic native species of special concern in Minnesota (VBWD, 1995). Only about 14 trout streams remain in the metropolitan area (MDNR, 1996), and so protecting the quality of Valley Creek is a critical component of maintaining aquatic biodiversity in the metropolitan area. Moreover, Valley Creek is tributary to the St. Croix River, a designated National Scenic Riverway and one of the cleanest large river systems in the contiguous United States (Waters, 1977). Maintaining the quality of the St. Croix River requires protection of its tributary watersheds. In short, Valley Creek and the St. Croix River are highly-valued resources that add to the quality of life and deserve protection.

A stream is sensitive to land use in its watershed because flows of surface water and groundwater converge on the stream and can efficiently carry suspended and dissolved substances to it. Urbanization and agriculture are two land uses known to alter stream hydrology and aquatic habitats by increasing loads of nutrients and suspended sediment (Klein, 1979; Schueler, 1994; Booth and Jackson, 1997; Spahr and Wynn, 1997; Wahl and others, 1997; Wernick and others, 1998). Accompanying siltation degrades trout habitat by blanketing the gravelly streambed needed for spawning and for production of the macroinvertebrates that compose the trout food base (Richards and Host, 1994; Rabeni and Smale, 1995; Waters, 1995). In addition, urbanization tends to increase runoff from impervious surfaces to streams, thereby increasing summer water temperatures above cold-water range (about 10—20¡ C) required by trout (Hicks and others, 1991; Schueler, 1994; Kemp and Spotila, 1997). Several studies have indicated that degradation to aquatic habitats occurs when impervious cover due to urbanization reaches a threshold of about 10—15% of the watershed surface (Klein, 1979; Schueler, 1994; Booth and Jackson, 1997). Urbanization is perhaps the greatest threat to watersheds in the St. Croix basin, and Valley Creek is at the eastern fringe of the rapidly urbanizing Twin Cities metropolitan area. The type and density of future development, the relative coverage of developed and undeveloped areas, and the magnitudes of their contributions to the groundwater and surface-water systems will determine the future health of the Valley Creek ecosystem. Watershed-scale studies are required to assess the integrated and cumulative impact of such development. Overall, the hydrology and biology of trout-bearing Valley Creek provide a sensitive, integrated measure of the effects of urbanization and other land uses in an area where, because of development pressures, such a measure is most needed.

Setting

Valley Creek has two main perennial branches, called here the North Branch and the South Branch, that combine to form a main stem before entering the St. Croix River just north of the village of Afton in southern Washington County (Figure 1). The present surficial watershed is about 45 km^2 (square kilometers); however, the creek captures groundwater from a significantly larger area. Because highly permeable soils in much of the watershed promote infiltration, overland runoff is minimized, and most of the time the creek is at baseflow, at which time virtually all flow in the creek results from groundwater discharge. The large proportion of groundwater feeding the stream is the main factor that keeps water temperatures cold in the summer, allowing trout to thrive. Parts of the main channel of Valley Creek are in a steep-walled bedrock valley that cuts deeply below the level of the surrounding sand plains, and during occasional extreme snowmelt or precipitation events, overland runoff can be severe and can erode substantial amounts of sediment into the stream. The riparian zone near the perennial reaches of Valley Creek is largely floodplain forest and shrubs that have revegetated the area during the past 30—40 years, although about 20 residential dwellings are within 100 m of the creek.

The surficial watershed of Valley Creek is within boundaries of three local jurisdictions: 86% in the City of Afton (39 km^2), 13% in the City of Woodbury (5.7 km^2), and 1% in West Lakeland Township (0.3 km^2). Present land use in the watershed is largely agricultural and rural residential, with several large tracts totaling almost 5 km^2 in the lower watershed set aside for preservation and educational purposes. A few scattered subdivisions exist with densities of one dwelling per one-half to five acres. The present total number of dwellings in the watershed is about 622. However, assuming existing agricultural and other lands become developed under present zoning regulations in Afton and Woodbury, this number would more than quadruple. Afton would absorb about 378 of these units, but most (about 1723) would be built in Woodbury, in the extreme western edge of the watershed (Pitt and Whited, 1999). The present impervious cover in the watershed has been estimated at about 2.7% (Pitt and Whited, 1999); if this increases commensurately with the increase in dwelling units, total watershed imperviousness could approach 12%.

Purpose and Scope

The purpose of the project was to determine potential effect of urbanization and other land uses on the hydrology of Valley Creek through two main approaches:

(a) by assembling baseline hydrological and spatial data on the creek and its watershed under present conditions, and by monitoring hydrological changes as urbanization continues, thus creating a long-term data base, and

(b) by modeling surface-water and groundwater flows in the watershed, first calibrating the models to present-day conditions and then running the surface-water model under scenarios of different potential urbanization patterns

The scope of the hydrological data collection effort was limited to about one year of data (late 1997 through 1998) collected during this study, plus data from grab samples collected by Valley Branch Watershed District from 1973—93. The spatial data was current as of about 1995. Model calibration was limited to the available hydrological and spatial data; model improvement would result from incorporation of longer-term data sets. While this project has lasted only two years, the goal is to maintain the hydrological data collection network operational for a minimum of 10 years (through 2007). While this project benefits water-resource management in the Valley Creek watershed most directly, Valley Creek may also serve as a high-quality standard of comparison for other metropolitan-area streams, thereby influencing management decisions in other watersheds and leading to a more widely applicable understanding of the effects of urbanization on small stream ecosystems.

Project Organization

The project was organized according to the tasks and products designed to meet the stated objectives, with the monitoring component (hydrologic and spatial data collection) providing basic data input to the modeling component (groundwater and watershed models) (Figure 2). The St. Croix Watershed Research Station (SCWRS) was responsible for overall project management and for hydrologic data collection and methods summary. The University of Minnesota Dept. of Landscape Architecture (UM-LandArch) was responsible for spatial data collection. The University of Minnesota Dept. of Biosystems and Agricultural Engineering (UM-BioAgEng) was responsible for watershed modeling in collaboration with UM-LandArch. Emmons and Olivier Resources (EOR) was responsible for regional groundwater data compilation and groundwater modeling in collaboration with SCWRS.

In addition to this Executive Summary (Report 1), the products include a compilation of spatial and hydrological data on CD-ROM and a series of five interpretive reports:

- Report 2: Methods of Hydrologic Data Collection
- Report 3: Surface-Water Hydrology
- Report 4: Atlas of Physiography, Hydrology, and Land Use
- Report 5: Groundwater Hydrology and Flow Model
- Report 6: Modeling the Effects of Urbanization on Surface Flows and Water Quality in the Valley Branch Watershed

The sections below contain the excerpted abstracts from these reports in turn.

REPORT 2: METHODS OF HYDROLOGIC DATA COLLECTION

Schottler and Thommes

Abstract

Beginning in July 1997, the St. Croix Watershed Research Station (SCWRS) received funding from the Legislative Commission on Minnesota Resources to initiate a program of long-term hydrological monitoring on Valley Creek in Afton, Minnesota. This report describes the site installation procedures, field techniques, and analytical methods used in the study.

Four automated monitoring stations were installed along branches of Valley Creek by the SCWRS, and a fifth station was installed near the mouth of Valley Creek by the Metropolitan Council Environmental Services division (MCES). Station 1 was located on the South Branch of Valley Creek, station 2 on the North Branch, and stations

3 and 4 on intermittent tributaries to the South Branch. Each of the stations recorded continuous measurements of stage, temperature, and specific conductance. Stations 3 and 4, being on intermittent tributaries, only recorded data during flow events. Stations 1—4 measured stage using a stilling well, float and shaft encoder; station 5 measured stage with a gas purge system (bubbler). A combination temperature/specific-conductance probe was secured in a PVC housing mounted in the stream and measured hourly averages of temperature and specific conductance. All stations were equipped with automatic water samplers and were programmed to collect discrete samples once per week to characterize baseflow and during flow events to characterize storm water. A datalogger was interfaced to each station to record measurements and control the automatic samplers. Equipment at sites 1—4 was housed in a 3 ft x 4 ft x 3 ft steel shelter box. Site 5 was designed to be a year-round station and included a heated walk-in shelter, 110VAC, and a modem hook-up.

In order to convert continuous stage measurements into flow, a stage-discharge rating curve was constructed for each site. Periodic measurements of discharge were made with either a current velocity meter or a dye-dilution measurement. At most sites the dye-dilution technique yielded more reliable results and was eventually adopted as the standard procedure for measuring discharge at all sites. The principle behind this method is that the downstream diluted concentration of dye added to the stream at a known rate is a direct function of stream discharge. A known concentration of rhodamine dye was added to the stream at a precise rate with a metering pump. Well-mixed, downstream concentrations of dye were measured with a benchtop fluorometer and used to compute discharge. The dye-dilution method was repeated at a variety of stream stages to construct a rating curve for each site. These rating curves will continue to be updated and verified for the duration of the monitoring study.

During weekly visits to the sites (bi-weekly during winter), a multiparameter water-quality sonde was used to measure dissolved oxygen, pH, temperature, and specific conductance. Since the sonde was calibrated in the lab before each use, the specific conductance values from the sonde were used to verify or modify the continuous *in-situ* probe measurements of specific conductance. Water samples were retrieved from the automatic water samplers, taken to the lab and stored a 4¡C. A 60-mL portion of each sample was sub-sampled and stored for total nutrient analysis. The remaining sample was filtered under vacuum through a 1- m glass-fiber filter, and 0.45- m polycarbonate filter. The mass of sediment trapped on the glass-fiber filter was used to calculate total suspended solids and baked a 550¡C to determine volatile suspended solids. The filtrate passing through the 0.45- m polycarbonate filter was split into a three 60-mL portions for dissolved nutrient, dissolved organic carbon, and dissolved inorganic carbon analyses. On selected samples two 20-mL sub-samples were taken and stored for cation and anion analysis, and a gravity filtered sub-sample was also collected for stable isotope (δ^{18}O and δD) analysis. A dual digestion method coupled with a dual channel nutrient autoanalyzer was used to measure concentrations of total and dissolved phosphorus and nitrogen. Dissolved organic and inorganic carbon were determined with a UV persulfate carbon analyzer. Cation and anion subsamples were sent to the University of Minnesota and analyzed with inductively coupled plasma-mass spectrometry. Isotope samples were also sent to the University of Minnesota and measured by mass spectrometry. Analysis for samples collected in 1997 and 1998 have been completed, and a database of the results is available (Almendinger and others, 1999).

REPORT 3: SURFACE-WATER HYDROLOGY

Almendinger, Schottler, and Thommes

Abstract

Valley Creek in southeastern Washington County, Minnesota, is one of the healthiest trout streams remaining in the Minneapolis-St. Paul metropolitan area. The watershed is presently mostly rural but faces potential urbanization in the coming decades. Trout streams are sensitive to land uses such as urbanization and agriculture that can degrade water quality. Urbanization can increase surface-water runoff from impervious surfaces into creeks, thereby increasing summer water temperatures above the range tolerated by trout, altering the macroinvertebrate community, and increasing loads of sediment, nutrients, and toxic substances (see reviews by Klein, 1979; Schueler, 1994; Booth and Jackson, 1997). The purpose of this report is to describe the surface-water hydrology of Valley Creek in order to document baseline conditions against which future changes may be gauged. This report concentrates on baseflow conditions in the creek because no major runoff events occurred during the present study period, which includes the latter half of 1997 and all of 1998. Monitoring will continue through 2007, contingent upon available funding. Selected data collected by the Valley Branch Watershed District from 1973-93 are included for comparison.

The surface-water hydrology of Valley Creek comprised measurements of water quantity (discharge and volume) and water quality at critical branch points along the creek, where automated stream-monitoring stations were established. Site 1 monitored the South Branch, site 2 monitored the North Branch, and site 5 monitored the mouth of the main stem of Valley Creek, about 1 km below the confluence of the south and north branches. Sites 3 and 4 monitored intermittent tributaries that did not flow during the study period. Grab samples were collected about weekly (bi-weekly during winter) and analyzed primarily for suspended solids and nutrients; a few samples were analyzed for major inorganic constituents (dissolved minerals).

Flow volumes were much larger than expected for a surficial watershed the size of that of Valley Creek, indicating that contribution from groundwater came from aquifers extending beyond the basin boundary. Steady groundwater contributions to the creek were indicated by extremely stable flows and stages, which varied typically within just a few centimeters from median. This stability was a result of the relatively level, highly permeable geologic deposits across much of the watershed, which facilitated infiltration and minimized overland runoff. Consequently, storm peaks were few and short-lived.

Some important water-quality variables were very different between the two main branches of the creek, the South Branch and the North Branch. These differences were due to the different water sources to the branches: the South Branch is fed by groundwater discharge, and the North Branch is fed primarily by outflow from Lake Edith. Because groundwater is relatively stable in temperature, the South Branch had much lower seasonal variation in temperature and reached a summertime maximum of only 16.5¡C, well within the range favored by trout (about 10—20¡C). In contrast,

because of summertime warming of Lake Edith, the North Branch exceeded 20¡C for about 22% of 1998 during the period from mid-May to mid-September, making this branch less favorable trout habitat. Biotic processes in Lake Edith also removed dissolved minerals from the water column, giving the North Branch lower concentrations of calcium, magnesium, bicarbonate, and silica than the South Branch. The loss of these dissolved minerals was tracked by specific conductance values, which declined during summer and recovered during winter in the North Branch relative to the South Branch. Both branches had relatively low values of total phosphorus and suspended solids. However, the South Branch had much higher concentrations of total nitrogen, a consequence of receiving nitrate-contaminated groundwater.

The maintenance of Valley Creek as a fine example of a trout stream will depend on guarding against at least two potential problems. First, inputs of overland runoff should be minimized, particularly from impervious surfaces that accompany development. The landscape is suitable for engineering practices that promote infiltration of storm water, rather than those that direct storm water directly to streams via gutters, storm sewers, and ditches. Such practices will minimize increases in runoff peaks and volumes, consequent channel erosion, and inputs of dissolved and suspended substances to the creek, although storm-water infiltration could affect groundwater quality. Second, inputs of eroded fine particulates (siltation) should be minimized, particularly in the South Branch. Because this branch is already well-fertilized with nitrates, additions of fine particulates with their associated bound phosphorus could spur over-abundant growth of aquatic macrophytes and algae. In addition, siltation destroys spawning habitat for trout and reduces the quality of the macroinvertebrate food source for trout. Finally, reducing nutrient inputs to Valley Creek is yet another positive step in improving the quality of the St. Croix River, a natural resource of national significance.

REPORT 4: ATLAS OF PHYSIOGRAPHY, HYDROLOGY, AND LAND USE

Pitt and Whited

Abstract

Structure of the Atlas

The landscape that people experience in today’s Valley Branch watershed has undergone great change. Many of these changes have occurred as a result of geologic processes, some are attributable to global patterns of climatic change, while others are a product of human occupation of the watershed’s landscape. Some changes occurred over hundreds of millions of years, some of the changes occurred over thousands or hundreds of years, while still others have occurred over a period of years or even months. Many of the changes that produced tangible manifestations in the contemporary landscape occurred well over 450 millions of years ago, while other changes directly affecting the present-day landscape are occurring in the contemporary milieu.

The *Atlas of Physiography, Hydrology and Land Use* in the Valley Branch watershed discusses the physical and cultural characteristics of the watershed. Physiography includes aspects of bedrock and surface geology that contribute to the making of landform and topographic slope. Weathering and erosion of the geologic conditions that comprise physiography, along with the accumulation of organic material, contribute to soil formation. Over time, surface water flowing across the land's surface further refines the sculpting of landform and slope. Together with climatic influences, physiography, soils and hydrology define the physical conditions within which biological conditions and ecological systems in the watershed evolved.

The atlas presents the physical and cultural characteristics from both a thematic and a historic perspective. Hopefully, the reader will obtain a sense of what is contained within the watershed as well as an understanding of how it came into existence. Material presented in the atlas is organized into the following topical areas:

- the evolution of the watershed's bedrock and surface geology;
- the development of the watershed's surface drainage patterns that have cut down into the watershed's geology;
- the effects of the geologic and hydrologic processes on creating topography within the contemporary landscape of the watershed;
- the development of vegetative cover within the watershed;
- the evolution of soils in different landscapes of the watershed;
- the development of the current pattern of land use, land cover and cultural settlement in the watershed;
- existing public policy toward land development within the watershed;
- a series of maps presenting alternative urbanization patterns throughout the entire watershed along with neighborhood design strategies that might be used in implementing the watershed-wide development; and finally
- a data dictionary explaining the derivation of each map.

The maps contained in the atlas pertain to those sub-basins defined by the Valley Branch Watershed District that are located south of Interstate 94. The combined spatial extent of these basins includes a large portion of the City of Afton, portions of the West Lakeland Township and the northeastern corner of the City of Woodbury.

Purpose of the Atlas

In the context of the Watershed Science: Integrated Research and Education Program, this Atlas of Physiography, Hydrology and Land Use relates primarily to Objective 1: Watershed Science in the Field. In addition to preparing the atlas, Objective 1 also:

- developed and implemented a comprehensive hydrologic and water quality monitoring program within the Valley Branch watershed;
- compiled hydrogeologic information and developed a model of ground water movement within the watershed; and
- developed two models to estimate the effects of different patterns of urbanization on surface hydrologic flows and water quality within the watershed.

While the atlas provided information of value to the ground water modeling activity, the three primary objectives guiding development of the atlas were:

¥ to compile watershed information needed to design and operate the surface hydrologic models;
¥ to compile watershed information needed to develop the alternative patterns of urbanization; and
¥ to display relevant geographic information compiled in the context executing the Watershed Science in the Field objective.

REPORT 5: GROUNDWATER HYDROLOGY AND FLOW MODEL

Almendinger and Grubb

Abstract

Valley Creek in southeastern Washington County, Minnesota, is one of the finest trout streams remaining in the Minneapolis-St. Paul metropolitan area. The two perennial branches, the North Branch (about 2.22 km long) and the South Branch (3.15 km), combine to form the main stem (2.45 km), which is tributary to the St. Croix River. The watershed is presently mostly rural but faces potential urbanization in the coming decades. Trout streams are sensitive to land-use practices such as urbanization and agriculture that can degrade water quality. Urbanization can increase runoff from impervious surfaces and reduce groundwater discharge, thereby altering the temperature regime of streams. In particular, midwestern trout streams depend on strong groundwater discharge to provide relatively clean water that remains cool enough in summer to support trout. The purpose of this study was to describe the groundwater hydrology of Valley Creek and to model the regional groundwater-flow system that delivers water to the creek.

The groundwater hydrology of Valley Creek comprised local stream-groundwater interactions and regional groundwater flow. Local stream-groundwater interactions were investigated by documenting the occurrence of springs, by measuring heads in shallow piezometers driven through the stream bed, and by measuring baseflow at selected points along the stream channel. Approximately 85% of the baseflow of South Branch Valley Creek was fed by springs and seeps in the upper 0.75-km headwaters reach, assuming baseflow measurements taken in spring 1999 were representative. All piezometers in this area had positive (upward) head gradients, indicating groundwater discharge into the stream channel. Nearly all the baseflow of North Branch Valley Creek appeared to derive from the outflow from Lake Edith, which was itself presumably fed by groundwater discharge. Piezometers along this branch had negative (downward) head gradients, indicating seepage of stream water out of the channel. One piezometer was dry, indicating perched conditions. Apparently, little groundwater discharge occurred in the North Branch below the lake outlet. In the main stem of Valley Creek, below the confluence of the North and South branches, a few springs and wetland seeps contributed groundwater, constituting about 11% of the baseflow at the mouth.

Regional groundwater flow was inferred from contour maps of potentiometric surfaces (well-water levels) for the major aquifers in Washington County. The aquifers that may influence groundwater discharge to Valley Creek are the Quaternary (glacial

drift) aquifer, the St. Peter aquifer, the Prairie-du-Chien/Jordan (PdC/J) aquifer, and the Franconia-Ironton-Galesville (FIG) aquifer. Groundwater divides were drawn for each aquifer layer by tracing groundwater highs (analogous to drawing a surficial watershed boundary by tracing topographic highs), beginning near the mouth of Valley Creek. The area enclosed by the groundwater divide in each aquifer is, in this report, referred to as the groundwatershed for that aquifer. As the channel of Valley Creek lies mostly within the elevation of the PdC/J aquifer, the groundwatershed for this aquifer was considered the most important contributor of groundwater to the creek and occupied an area of about 60—80 km^2 (23—30 mi^2). This area was significantly larger than the surficial watershed (about 44 km^2, or 17 mi^2), which could help account for the abundant baseflow of Valley Creek. In addition, the FIG aquifer may also be an important source of groundwater to the creek, although data were too sparse to construct a groundwatershed for that aquifer.

A regional analytic-element groundwater-flow model was constructed for the Valley Creek area with the MLAEM modeling program, based on regional template models developed by the Minnesota Pollution Control Agency and the South Washington Watershed District. The model had three layers, approximately representing the Quaternary (layer 1), the St. Peter (layer 2), and the PdC/J (layer 3) aquifers. The model was calibrated to measured baseflows in selected reaches of Valley Creek and to measured groundwater levels as generalized by the maps of potentiometric surfaces. Model results indicated that the layer 3 groundwatershed covered about 60 km^2 and corresponded closely in size, shape, and position to that mapped for the Prairie du Chien aquifer. Groundwater travel times (the time it takes groundwater to reach the creek) over most of the groundwatershed were about 30—40 years, but ranged from about 10 years within 2—6 km of the creek to about 60—70 years at the farthest boundaries of the groundwatershed. Because most of the groundwater reaching Valley Creek is apparently relatively young, perhaps less than 30—40 years since the time of infiltration, it may contain anthropogenic tracers and pollutants, such as nitrates.

Valley Creek has remained a fine trout stream probably because of its large baseflow component, which is derived over a relatively large groundwatershed. A large baseflow seems critical in giving the creek resilience to short-term disturbances, such as extreme floods or siltation events. Strong baseflow can promote recovery of the stream to pre-disturbance conditions by helping to wash away the dissolved and particulate inputs from such disturbances. Urbanization has been documented to reduce baseflows. Because the groundwatershed of Valley Creek extends to the north and west into rapidly urbanizing areas, care should be taken to minimize practices that reduce infiltration in these areas. In short, maintaining the quantity of groundwater discharge to Valley Creek will be a key factor in keeping it a healthy trout stream and allowing it to recover from potential impacts, should they occur.

REPORT 6: MODELING THE EFFECTS OF URBANIZATION ON SURFACE FLOWS AND WATER QUALITY IN THE VALLEY BRANCH WATERSHED

Whited, Jahnke, Wilson, and Pitt

Abstract

Models are useful, and perhaps essential, tools for evaluating the impact of urbanization on runoff depth and sediment yield. They are nonetheless imperfect tools, each model having different strengths and limitations. The Soil and Water Assessment Tool (SWAT) and the Water Erosion Prediction Project (WEPP) models were used in this study. These are two widely used state-of-the-art models. The strengths of SWAT and WEPP are their relatively detailed representations of upland processes, especially related to agricultural practices. A limitation of the model effort is the incomplete representation of stream processes. In addition, the impact of urbanization on nutrient and pesticide loadings is not considered in the models.

Although SWAT and WEPP were originally developed for agricultural watersheds, they use different modeling approaches for important upland processes. These differences include their representation of spatial variability within a hillslope and their algorithms for predicting infiltration and soil erosion. For the SWAT simulations, the Valley Branch Watershed was divided into subbasins. Data layers compiled with ARCVIEW were used to determine the input parameters for each subbasin. For the WEPP simulations, the Valley Branch Watershed was also divided into subbasins. In addition, the hillslopes within these subbasins were divided into segments to represent possible spatial variabilities of parameters along hillslope transects. Routines were needed to link ARCVIEW data bases with the WEPP model. These routines were successfully developed and used to determine efficiently the input parameters of WEPP.

Both models were evaluated by using sensitivity analyses and by comparing the predicted values to observed data for the Valley Branch Watershed and nearby areas. The WEPP model was sensitive to changes in land use conditions. The SWAT model was relatively insensitive to several subsurface flow parameters. With the proper selection of input parameters, both models were generally able to predict reasonable runoff depths and sediment yields for the Twin Cities region. Both models, however, underpredicted the base flow for the Valley Branch Watershed. The observed base flow likely includes discharge originating from areas outside the watershed boundaries (see Reports 3 and 5), and therefore accurate representation of base flow was not possible.

Five different neighborhood development scenarios were considered in the study. High density consisted of three dwelling units per acre gross and net density. This density was simulated with and without storm water management practices (ponds). Five-acre gross and net densities were also simulated with and without ponds. The fifth development scenario (one-third acre) was a five-acre gross density clustered at 3.3 dwelling units net density with ponds.

The impacts of urban development were first determined using detailed design scenarios compiled for Section 19. Transects were drawn through each scenario to determine parameters for flow over segments of grass and pavement and for possible concentrated flow in curb and gutters. Annual runoff depths and sediment yields were estimated from these transects using the SWAT and WEPP models. Results were

adjusted to account for the impact of ponds in the design scenarios. By using the transect/pond approach, prototypical results were obtained for each development scenario. A development soil parameter set, corresponding to a single cover and soil type, was created to obtain the same predicted runoff depth and sediment yield as those from the prototypical representation. The impacts of urban development for other areas in Valley Branch watershed were simulated by using the appropriate development soil. This greatly simplified the prediction of runoff depths and sediment yields for the urban development scenarios.

The simulation results were evaluated for five subwatersheds: (1) Section 19, (2) Lake Edith, (3) Fahlstrom Ponds, (4) North Valley Branch, and (5) South Valley Branch. Impacts were assessed by considering the percent change in runoff depth or sediment yield from existing conditions. Different trends were frequently predicted using the WEPP and SWAT models. The WEPP results were considered superior because of the improved representation of hillslope processes. Overall assessment of the impact of urban development was therefore based on the WEPP simulations.

The WEPP model predicted an increase in runoff depth for the high-density development scenarios (with and without ponds) for all five subwatersheds. This increase was the result of (1) the high proportion of impervious area, and (2) the presence of curb and gutters to concentrate runoff. The five-acre (with and without ponds) and the clustered one-third acre development scenarios resulted in a decrease in runoff depth. This trend resulted from (1) the conversion of agricultural lands to grassland, (2) the low percentage of impervious area, and (3) the lack of curb and gutters to concentrate flow. The largest and smallest runoff depths were predicted for the high-density and the clustered one-third-acre-with-ponds scenarios, respectively.

The WEPP model predicted a decrease in sediment yield for all urban development scenarios for all five subwatersheds. This decrease resulted from (1) no erosion from impervious areas, (2) the low erosion rates from grassland, and (3) effectiveness of ponds to trap sediment. In general the greatest reduction in sediment yield was obtained for the high-density (with ponds) development scenario, and the smallest reduction with the five-acre (without) pond scenario. Even though the runoff depth is largest for the high-density scenario, this large runoff depth occurs on a non-erodible (impervious) land cover and therefore does not substantially increase the sediment yield for the scenario.

CONCLUSIONS

In aggregate these reports confirm that Valley Creek has thus far remained a high-quality stream, with the possible exception of the high total nitrogen content of the South Branch. Erosion should be particularly guarded against in this branch because of the potential of particle-bound phosphorus to spur over-abundant growth of aquatic vegetation, and because of the detrimental effect of siltation on trout habitat. Recharge in the groundwatershed of Valley Creek should be protected to maintain large baseflows in the creek. Because the groundwatershed extends into already rapidly-urbanizing areas, practices that maximize infiltration and minimize stormwater runoff should be encouraged. Finally, increased runoff from high-density development should be avoided, as this runoff could increase stream temperatures beyond the range tolerated by trout and other desired species.

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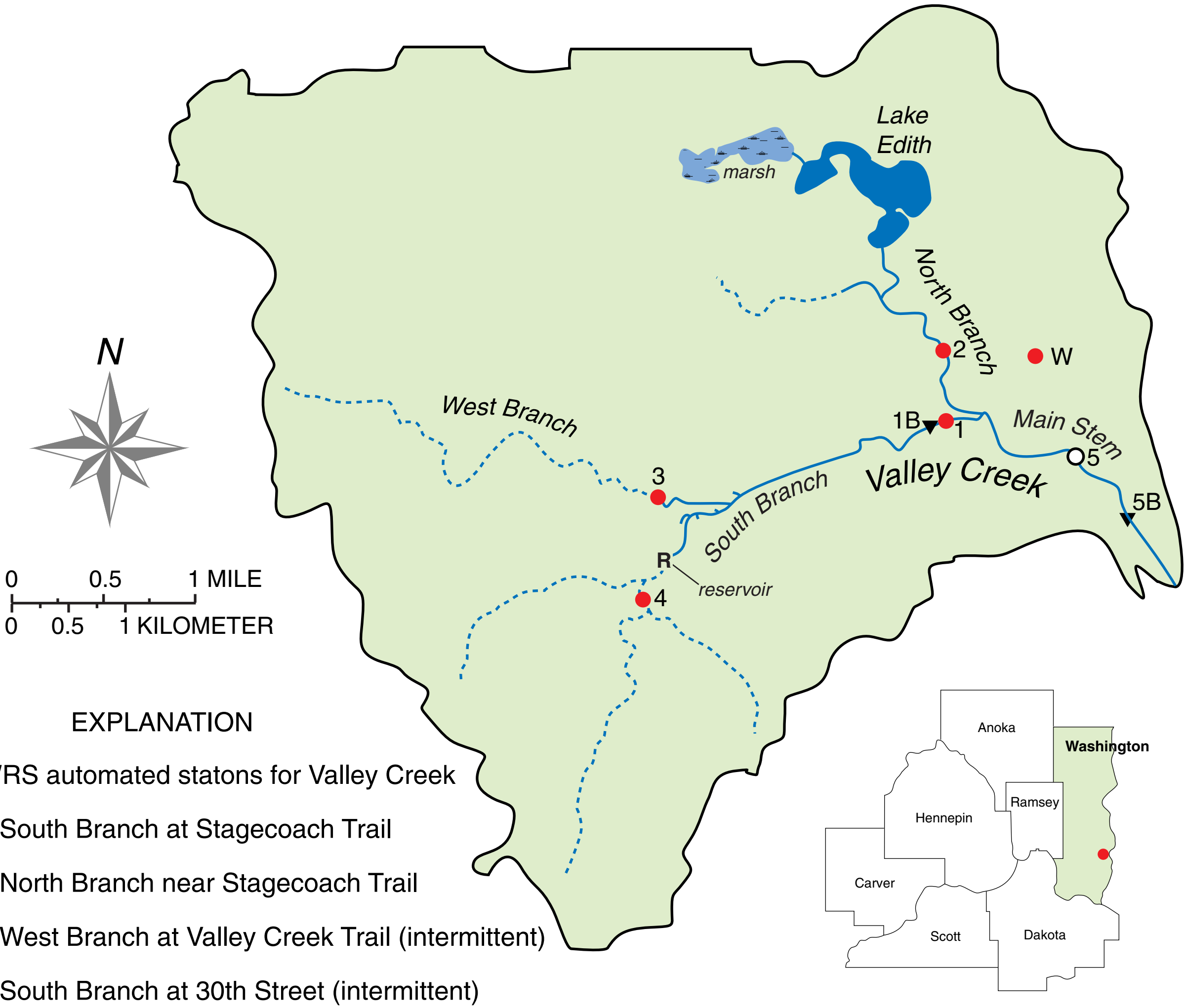
FIGURES



EXPLANATION

● SCWRS automated statons for Valley Creek

1 South Branch at Stagecoach Trail

2 North Branch near Stagecoach Trail

3 West Branch at Valley Creek Trail (intermittent)

4 South Branch at 30th Street (intermittent)

W Automated weather station

○ Met Council automated station on Valley Creek

5 Main Stem at Putnam Boulevard

▼ VBWD (Barr) sampling sites on Valley Creek

1B South Branch at Stagecoach Trail (site B in VBWD Water Management Plan)

5B Main stem at hwy 95 (site C in VBWD Water Management Plan)

SCWRS, St. Croix Watershed Research Station
Met Council, Metropolitan Council Environmental Services
VBWD, Valley Branch Watershed District
Barr, Barr Engineering

Approximate location
of Valley Creek watershed
in Twin Cities metropolitan area

Figure 1. Valley Creek Watershed and locations of long-term monitoring sites

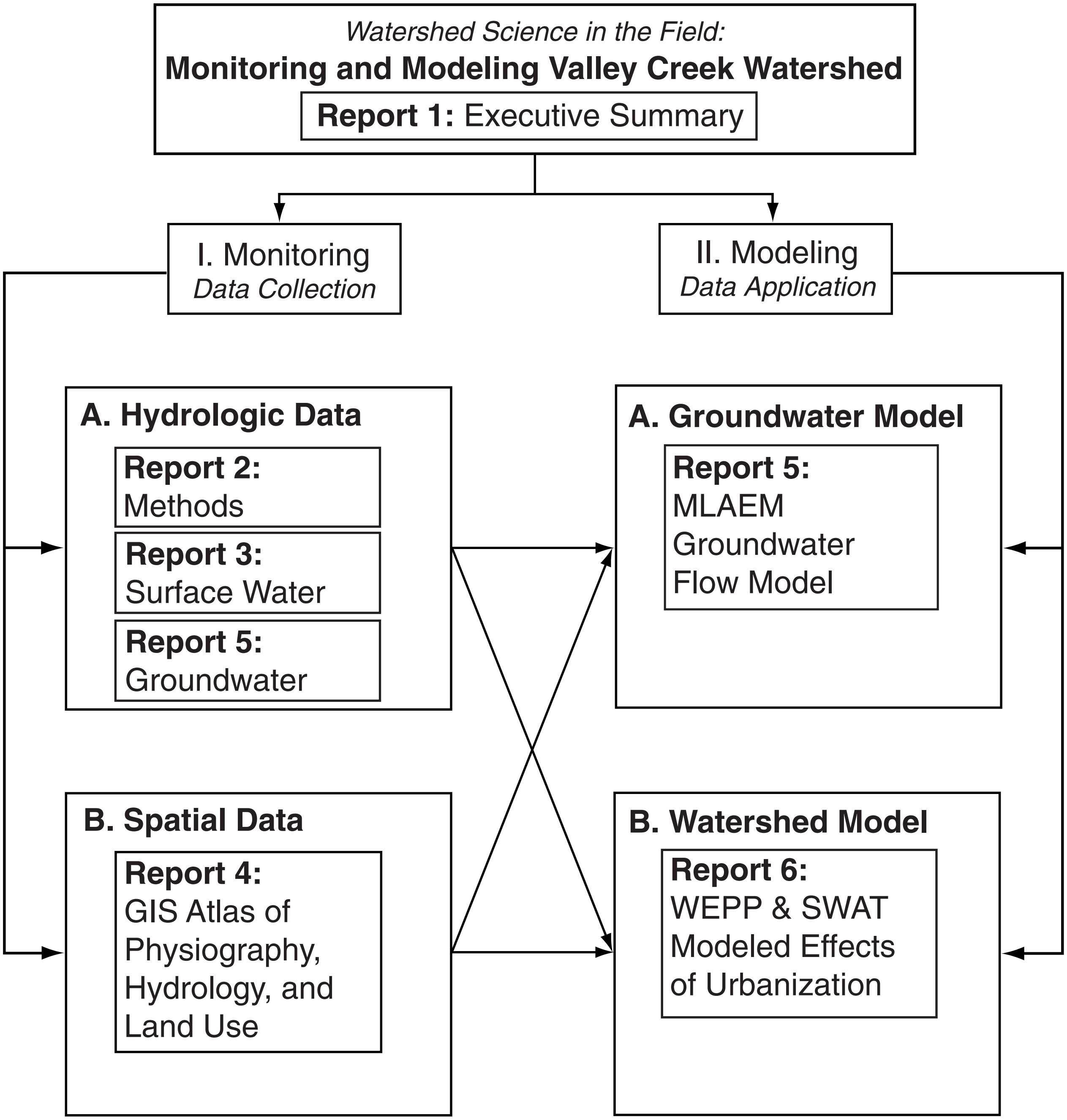


Figure 2. Project organization