Addressing the Challenges of Identifying, Defining and Mapping Natural Infrastructure

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Abstract
The following paper provides an overview of the Natural Infrastructure (NI) Project of Southwestern Pennsylvania. The NI Project is a multi-year regional planning effort whose primary focus is enhancing the region's depressed economic vitality by leveraging its natural resources. The NI Project uses GIS to analyze and assess the full-range of uses of the natural world, including mineral reserves, water supply, habitat areas, landfills, agricultural resources and recreational opportunities such as trail corridors. These GIS-based analyses provide a foundation for developing physical planning and economic development strategies.

The NI Project's data, 95% of which was created through specialized GIS analyses, included over 125 data layers and 800 data attributes, covering a land area of 4.3 million acres. Queries built upon facts and scientific input were developed to generate new GIS layers from existing information. This derived GIS data allowed for detailed analyses and was used to identify, prioritize and resolve conflicts between NI uses. The resulting policy framework improves regional economic vitality by limiting the loss of resources and optimizing potential development areas.

Introduction
American regions have historically developed in concert with their natural terrain, features and resources. The economic vitality of a region was often created by its proximity to plentiful natural resources such as water, woodlands and farmland. However, over the past forty years, the economic focus of many American cities has shifted from industrial production to health, financial and other service-based industries. This shift has also altered the manner with which a region utilizes its natural resources. While these resources are no longer the primary fuel of regional economies, they do often define the region's character and attractiveness. This new

role has reinforced the importance for economically vital regions to offer clean and abundant water supplies, affordable energy and a high quality of life.

Pittsburgh and the southwestern corner of Pennsylvania provide an illustration of how a region can leverage its natural resources, or natural infrastructure, to enhance economic vitality. The region's industrial-age legacy and its population losses have left its remaining 2.6 million residents with numerous infrastructure issues such as $3 billion of EPA-mandated sewer improvements, the loss of prime farmlands and woodlands as well as the impact of abandoned coal mines. These issues, when combined with the region's large size (6,000 square miles) and its segmented government structure (9 counties with 528 municipalities), have made solving macro-scale regional problems political and economic challenges.

A group of Southwestern Pennsylvania leaders are attempting to address some of these issues through a process that is participatory, holistic, science-based and, most importantly, regional in scale and scope. The Southwestern Pennsylvania Commission (SPC), the Pennsylvania Department of Conservation and Natural Resources (PA DCNR), the Pennsylvania Environmental Council (PEC) and The Heinz Endowments have formed a partnership to identify, evaluate and initiate discussion on the use of the region's natural infrastructure. A Technical Team of regional planners, landscape architects, civil engineers, GIS experts, economists, ecologists, hydro-geologists and archeologists support this partnership and completed the first phase of the Natural Infrastructure Project in the Summer of 2005.

Natural Rather than Green

While several regions in the United States have launched green infrastructure initiatives or have developed green infrastructure plans, the Natural Infrastructure Project differs dramatically from these efforts. The term *green infrastructure* has become synonymous with green space or open space and is often linked with recreational planning efforts. *Natural infrastructure*, as defined herein, encompasses a broader definition. Natural infrastructure takes a comprehensive view of all uses of our natural world and attempts to strike a balance between ecology, cultural heritage, human use and economics. Consequently, the term natural infrastructure includes traditional green infrastructure uses such as trails, agriculture, forestry, hunting, camping and fishing – but it also encompasses natural resources such as coal mining, aggregate extraction, pubic water supply, landfills and other public services.

A Comprehensive Approach

The Natural Infrastructure Project consists of three major work components and a multi-faceted public participation process. The components include:

1. Regional Case Studies

2. Natural Infrastructure Analyses

3. Conflict Analysis and Resolution

A comprehensive participatory process was developed to obtain a diverse range of perspectives and input regarding the use and value of natural infrastructure. The participatory process consisted of:

- A Steering Committee, with representatives from each county to guide the Project's direction and decisions

- County-based technical advisory groups including professional practitioners such as county planners and GIS analysts, state agency representatives and other government-based technical specialists

- A series of county-based community meetings used to obtain public insights regarding each county's specific natural infrastructure data

- Periodic briefings held with County Commissioners designed to build on SPC's role in the region as the metropolitan planning organization and to empower the Project through County Commissioner involvement

Regional Case Studies: Natural Infrastructure's Role in Economic Vitality

In order to identify economically vital regions that had significant natural infrastructure planning activity, the Technical Team analyzed 59 American and Canadian metropolitan areas. To measure economic vitality, the Team created an index of population growth, job formation and gross national product; to measure natural infrastructure quality, the Team created an index of natural infrastructure resources, publicly accessible land and climatic conditions. The indices pointed to three outstanding areas or case studies: Raleigh-Durham-Chapel Hill (the Research Triangle), Minneapolis-St. Paul and Boston. The Technical Team then interviewed local experts in these regions to provide qualitative perspectives on their natural infrastructure.

1. Just as the quality of natural resources and amenities differs between regions, their relative importance related to job creation and resident attraction also varies. The Research Triangle believes that the quality of its natural infrastructure is directly tied to the attraction of residents and talent. Minneapolis-St. Paul and Boston feel that natural infrastructure plays a lesser role attracting residents and talent. However, the experts in all three regions agree that natural amenities are an important factor in retaining quality residents and talent. In other words, rivers and trails alone may not necessarily bring new residents to a region, but they do help keep current residents from leaving.

Minnesota's St. Croix River is considered one of the finest fly fishing rivers in the world. Because of suburban growth, portions of the river currently suffer from the over withdrawal of water for municipal use. This over withdrawal has lowered water levels, has reduced fish habitat and is impacting the local tourism economy.

2. Each of the case study regions are suffering from shortages in critical natural infrastructure resources such as water, aggregates for construction and agricultural land. These shortages have limited the ability of the regions (or portions thereof) to sustain economic vitality and population growth. Most importantly, the regions are being forced to respond to their crises in a reactive rather than proactive manner. Consequently, the solutions that have been proposed are more costly and less effective in the long-term.

3. Southwestern Pennsylvania has a unique opportunity to leverage the Natural Infrastructure Project into one of the ultimate competitive advantages for a region. The Project will allow the Southwestern Pennsylvania region to:

    - Help ensure that the region does not suffer from a shortage of natural infrastructure resources
    - Create efficiency and affluency by reducing costly grey infrastructure solutions and by maximizing the economic value of readily available natural infrastructure resources
    - Document the locations of the region's precious natural infrastructure resources and to develop strategies to optimize their long-term use.

Natural Infrastructure Analyses: Identifying Our Natural Infrastructure Resources

A geographic information system (GIS) has been the principal tool used to identify, map and analyze the Southwestern Pennsylvania region's natural infrastructure resources. SPC's GIS database, prior to the initiation of the Natural Infrastructure Project, contained approximately 25 unique data layers. This data, however, addressed only about 40% of the region's natural infrastructure and required supplemental data.

Two methods were used to expand SPC's GIS data. The first method focused on factual data that is made available by government agencies such as the Pennsylvania Department of Environmental Protection (PA DEP), the US Geological Survey (USGS), the US Department

Natural Infrastructure Uses

Public Services

- Groundwater Recharge Areas
- Stormwater Filtration Areas
- Ground Water Supply
- Surface Water Supply
- River Water Supply
- On-site Septic Soils
- Constructed Wetlands
- Landfills
- Transportation

Products

- Agriculture
- Forestry
- Aggregate Extraction
- Coal Reserves
- Oil/Natural Gas Reserves
- Solar Energy Production
- Hydro-electric Energy Production
- Wind Power Production

Habitat

- Biological Diversity Areas
- Brook Trout Habitat
- Warm Water Gamefish Habitat

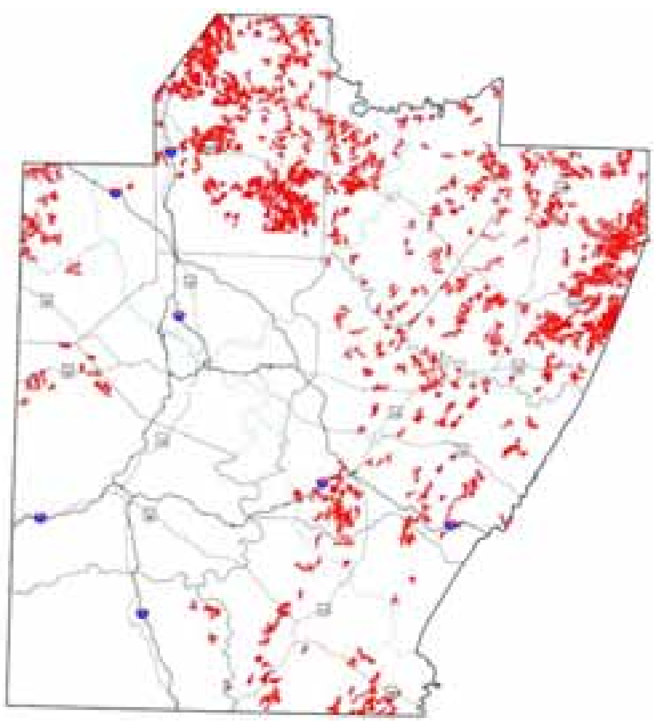
Human Use

- Trails
- Hunting
- Primitive and Vehicular Camping
- Motorboating and Sailing
- White-water/Flat-water Canoeing, Kayaking and Rafting
- Downhill Skiing
- Cultural Resources
- Aerial Sports

of Energy (US DOE) and the US Department of Agriculture (USDA). Examples of this data include the USDA's STATSGO soils database and digital topography compiled by the USGS.

The second method of expanding the SPC GIS database involved the creation of derived data based on the use of the region's various natural infrastructure resources. The derived data models the location of approximately thirty natural infrastructure uses and has been created through a series of specialized GIS analyses. The specialized analyses are based on the general physical and environmental characteristics of each natural infrastructure use as well as the basic attribute information that is available in the original GIS database and the supplemental data. The analyses allow the Technical Team and the Steering Committee to determine the land most suitable for each natural infrastructure's use. As a result of the Natural Infrastructure analyses, the SPC GIS database has been increased to more than 125 layers and includes nearly 800 new attributes. Much of the new data has been distributed to the county planning agencies and is currently being used in the preparation of several county comprehensive planning efforts.

The following is an example of a specialized GIS analysis and modeling process. The illustration below depicts lands suitable for landfills. The illustration was created with ESRI®'s ArcGIS 9.2® and Spatial Analyst® software and is based on the PA DEP general regulatory requirements for landfills. Soils, geology, topography, hydrology and land coverage layers were divided into a grid of 6,000,000 1-acre squares. The suitability of each square for use as a landfill was determined through a series of GIS queries that:



1. Identify suitable physiographic features such as land cover, slopes and geology;

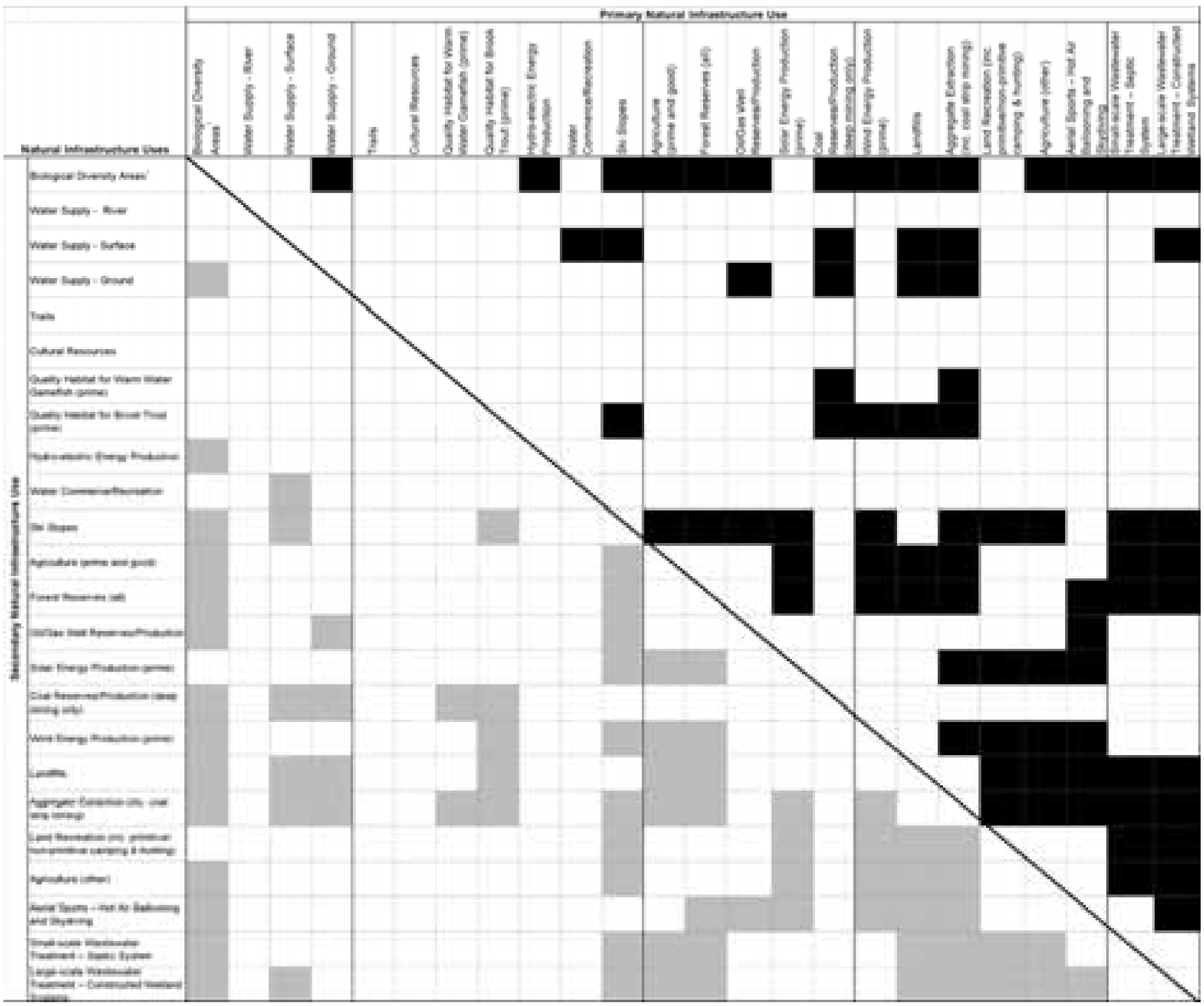
2. Eliminate proximity to rivers, streams, lakes, wetlands, floodplains and schools; and

3. Evaluate environmental constraints such as depth to bedrock and depth to water table.

The lands suitable for landfills, illustrated by the areas shaded red, are the product of the query process. Plotting the location of the region's existing landfill facilities shows that each landfill falls within the shaded areas, validating the integrity of the modeling process. One of the region's landfills has been recently decommissioned because of its long history of environmental violations and impacts. Appropriately, this facility is located outside of the shaded areas.

Conflict Analysis and Resolution: Weighing the Conflicts

As a result of the region's natural infrastructure analyses, more than 780 unique relationships between the various natural infrastructure uses have been defined. Of these relationships, it has been determined that 75% can co-exist or co-habitate within the same geographic area. The remaining 25% are in conflict with one another and cannot co-exist simultaneously. One example of such a conflict is the relationship between surface water supply and landfills. When these two particular uses are found to be suitable in the same geographic area, only one can be used while the other is lost.



Moreover, each use identified in the natural infrastructure analysis has a different reserve capacity or life span. Some natural infrastructure uses, such as agriculture or ground water supply are renewable and therefore can be used in perpetuity with proper management. Other uses, such as coal mining, are non-renewable and have finite life spans. To estimate these life spans, the Technical Team utilized a customized methodology based on ArcGIS® and Spatial Analyst® to assess the reserve capacity of each use. In the case of landfills, for instance, the Technical Team divided the amount of land suitable for landfills (as identified by the previous modeling process) by the region's current rate of landfill consumption to obtain the number of years to depletion. The resulting estimate, around 3,400 years, indicates that landfills are an abundant natural infrastructure use.

Equipped with an understanding of conflicts and the physical and economic capacity of each natural infrastructure use, the Technical Team has completed a first pass at formulating a resolution strategy. The initial strategy weighs or balances the importance of natural infrastructure uses based on their significance and abundance. This balance reflects the region's values as well as lessons gleaned from the regional case studies.

The conflict matrix outlined below summarizes the Technical Team's initial resolution strategy. A white square indicates a relationship without conflict between two natural infrastructure uses. A grey square indicates a relationship where the primary natural infrastructure use takes precedence in a conflict; a black square indicates a relationship where the primary natural infrastructure use is precluded in a conflict.

Let's return to the land suitable for landfills example for a demonstration of the resolution strategy. The intent of the conflict matrix is to document and resolve potential conflicts between uses. For example, the column for landfills (shown at right) defines two sets of conflicts. The first set consists of six conflicts where landfills do not take precedence (indicated by a black square) and are therefore precluded.

Natural Infrastructure Use	Landfills
Biological Diversity Areas[1]	
Water Supply - River	
Water Supply - Surface	
Water Supply - Ground	
Trails	
Cultural Resources	
Quality Habitat for Warm Water Gamefish (prime)	
Quality Habitat for Brook Trout (prime)	
Hydro-electric Energy Production	
Water Commerce/Recreation	
Ski Slopes	
Agriculture (prime and good)	
Forest Reserves (all)	
Oil/Gas Well Reserves/Production	
Solar Energy Production (prime)	
Coal Reserves/Production (deep mining only)	
Wind Energy Production (prime)	
Landfills	
Aggregate Extraction (inc. coal strip mining)	
Land Recreation	
Agriculture (other)	
Aerial Sports – Hot Air Ballooning and Skydiving	
Small-scale Wastewater Treatment – Septic System	
Large-scale Wastewater Treatment – Constructed Wetlands	

The second set of conflicts focuses on five different natural infrastructure uses. In this set of conflicts, landfills take precedence (as indicated by a grey square) and outweigh the other uses in terms of importance because the reserve capacity for landfills has been greatly reduced by the resolution of the first set of conflicts. After all conflicts have been addressed and the reserve capacity for landfills has been adjusted, the region still has more than 600 years of capacity available.

The landfill example demonstrates the dynamic nature of the resolution strategy. The example illustrates how the importance of a natural infrastructure use can be weighed relative to its own reserve capacity as well as to the reserve capacity of other natural infrastructure uses. Through this process, a resolution strategy can be formulated and a practical balance can be struck between all conflicting natural infrastructure uses.

Reserve Capacity - Years to Depletion*

Natural Infrastructure Use	Pre-Conflict Analysis	Post-Conflict Analysis
Forestry	71 years	61 years
Coal Production	121 years	80 years
Water Supply – Surface	Renewable	Renewable
Water Supply – River	Renewable	Renewable
Landfills	3,451 years	603 years
Wind Energy Production	Renewable	Renewable
Aggregate Extraction	3,413 years	450 years

*Based on the region's current rates of consumption

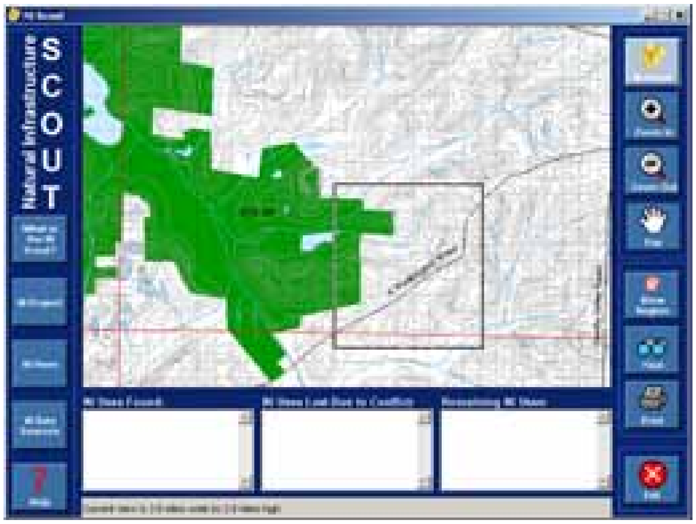
The structure of the resolution strategy provides a natural infrastructure planning framework that can be adjusted for use at any scale or can be utilized within any region. The framework is designed to be scaleable and consequently can be easily customized for use at a regional, county, municipal or site-specific level. Moreover, the framework can be modified to incorporate data at varying levels of specificity. This allows regional-scale information to be integrated with site-specific information.

Finally, the resolution strategy provides a process for potential mitigation measures to be identified. These measures, when employed, can eliminate or minimize a conflicting relationship without any natural infrastructure use being lost or precluded. Mitigation measures such as riparian buffer preservation, development setbacks and impervious surface regulations can be incorporated into the resolution strategy in order to allow both conflicting uses to co-exist simultaneously without harming the other use.

NI Scout: An Interactive GIS Planning Tool

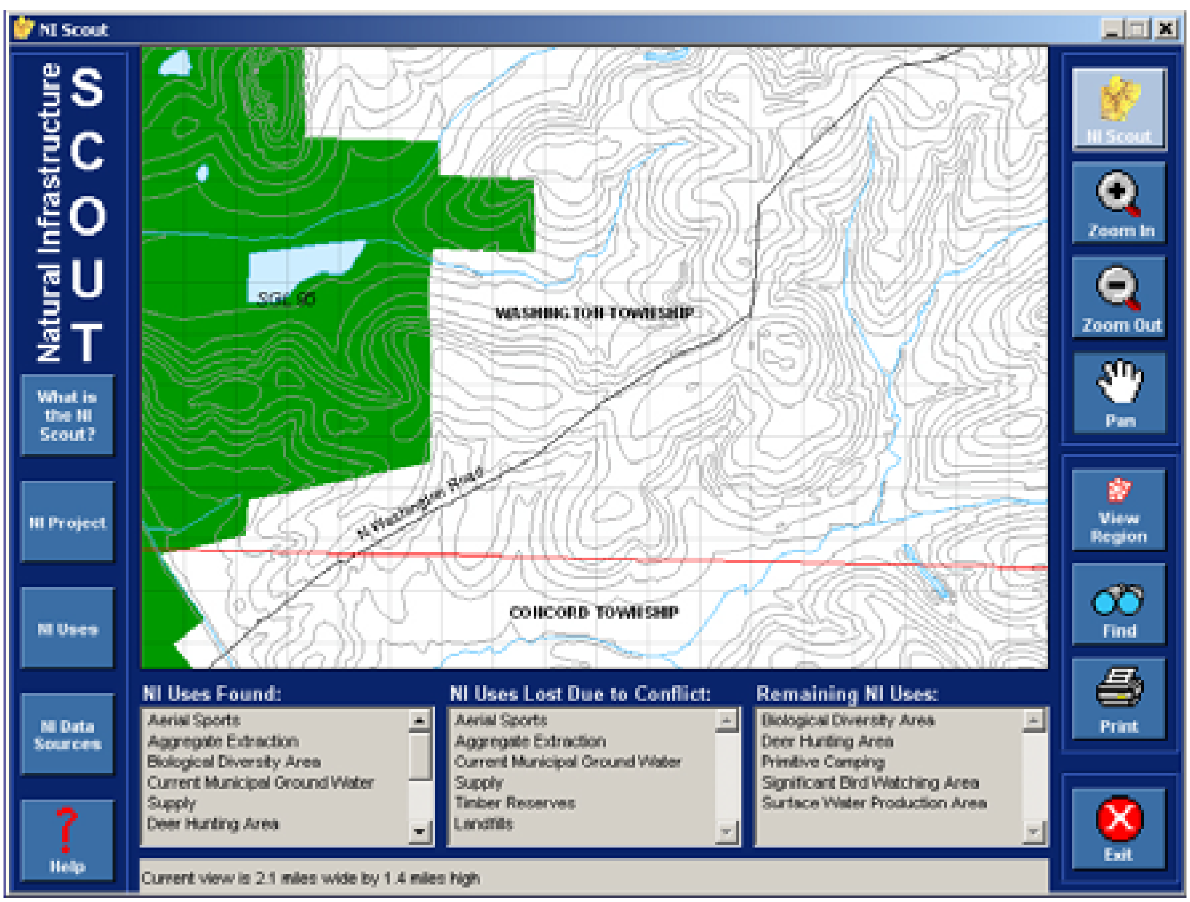
As the technical planning process began to conclude, the NI Project's stakeholders sought to develop a low-cost, low-technical skill medium with which to share data and information. County and local planners, planning commissioners, environmental advocates, watershed groups, conservation organizations, land trusts, extractive industries, foresters, land developers and government agents were anticipated users of the NI data. The technical sophistication, computer resources and skills of this broad base of constituents varied dramatically. The Technical Team and stakeholders explored several concepts for sharing and dispersing data and ultimately settled on the creation of a "share-ware" based GIS data viewer that could be economically reproduced and distributed by CD-ROM.

This data viewer, known as the NI Scout, allows users to interactively visualize any one of the GIS layers created to document the location of the Southwestern Pennsylvania region's NI uses. Moreover, the NI Scout permits users to query the relationships between selected NI uses and to view the results of the resolution strategy that has been forged. The basic NI Scout database and search engine is built on ESRI®'s ArcReader® platform and has been further customized through the Microsoft® .NET® software developer package.



The NI Scout consists of three separate interfaces. The first provides a map box to graphically view the boundaries of the various GIS coverages. Line weights, line symbology and labeling have been calibrated and synchronized for dynamic display at all map scales. Geographic locations can be selected using map tools or through a selection of pre-determined landmarks such as State Parks or municipalities.

The second interface allows the user to develop specific database queries as related to the location and relationship of the full range of NI uses. To simplify the calculations required at run-time, all query relationships have been pre-calculated. Once a query



has been created, the user is presented with the NI uses that are currently found on the selected site as well as the results of the resolution strategy if any conflicts exist between the existing NI uses.

The final interface enables the user to browse through a series of resource links regarding the NI Project. This interface can be accessed at any point in time during a user session and provides explanations of natural resources, conflicts and stakeholder involvement.

Conclusion

While the strength and vitality of a region has historically been measured by its economic growth and the abundance of its industries, the paradigm of economic vitality has shifted over the past 20 to 30 years. Economically vital regions such as North Carolina's Research Triangle, Minneapolis-St. Paul and Boston, have discovered that in order to provide for and to retain businesses and residents, a region must possess clean and abundant water resources, affordable energy, available construction materials, unique cultural resources and substantial natural amenities. These assets ultimately create a competitive edge by elevating a region's quality of life and its economic vitality.

In response to Boston's on-going water crisis and escalating water treatment costs, the U.S. Army Corps of Engineers purchased land surrounding the headwaters of the Charles River. The Boston initiative, modeled after New York City's purchase of land in the Catskill Mountains, has not been as effective because it was completed in the mid-1970's after large portions of the watershed had already been developed.

Although many regions comprehensively plan transportation networks or sanitary sewer improvements, very few regions have documented the location and extent of their natural infrastructure resources let alone planned for their use in a comprehensive or proactive manner. Narrowly defined efforts, such open space or greenway plans, can miss the broad synergies and conflicts that often exist between natural infrastructure uses.

The Natural Infrastructure Project for Southwestern Pennsylvania is an attempt to establish a new direction in regional planning and to stimulate economic vitality. The Project provides the region with a unique opportunity to identify key natural infrastructure uses and to define a balanced approach for the preservation, conservation and consumption of those uses. The Project creates a forum for the region's residents, business enterprises and political leaders to discuss issues and to define values. Through dialogue such as this, the region will be able to establish the ultimate competitive advantage by minimizing conflicts between natural infrastructure uses and by maximizing the availability of critical resources.

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Appendices

NI GIS COVERAGES

NI GIS covers the counties of Allegheny, Armstrong, Beaver, Butler, Fayette, Greene, Indiana, Washington and Westmoreland. NI uses ArcView GIS software. NI uses the PA Stateplane South projection, NAD 1983, and the units are in feet.

GIS Coverage	Coverage Type	Coverage Description
ABND_MINE_PROBLEM	-(Point)	Abandoned Mine Land - Coal Mine Related
AEU_83	-(Polygon)	Animal Equivalency Units
ALLARM_199911	-(Point)	Alliance for Aquatic Research Monitoring (Allarm) Pennsylvania Water Quality Database
AMD_FISHERIES	-(Line)	Fisheries Impacted by Acid Mine Drainage
BEDROCK	-(Polygon)	Bedrock Geology of Pennsylvania
DIKES	-(Line)	Contacts, Dikes, and Fault Lines
FAULT_LINES	-(Line)	Fault Lines
CRUSHED_STONE	-(Point)	Crushed Stone Operations
DAMS	-(Point)	Dam Locations
DCNR_TRAIL	-(Line)	DCNR Trails
DRASTIC	-(Grid Coverage)	Drastic Scores to Ground Water vulnerability to Pollution
FISH_OCCURRENCE (Also by Species)	-(Point)	Fish Species Occurrence Database
FOR_DENSITY	-(Grid Coverage)	Forest Density
FOREST	-(Grid Coverage)	Forest Type
GAP_FISH (Shapefiles are named by individual species)	-(Polygon)	Pennsylvania Conservation Gap Fish Habitat Model
HUNTINGR3	-(Polygon)	Publicly Controlled Hunting Lands
LONGWALL_MINING	-(Polygon)	Manage Surface Longwall Panels
NASQAN	-(Point)	A point coverage of Stations
NAWQA (SW9194X020)	-(Point)	Surface Water Sampling Sites
OAGFLDS	-(Polygon)	Oil and Gas Fields
OAGWELLS	-(Point)	Oil and Gas Wells
PAGIS WELLS		
DEP	-(Point)	Public Water Supply Wells Database
GWSI	-(Point)	Ground Water Site Inventory Database
SPRINGS	-(Point)	Quality of Water (QW DATA) Database
WWI	-(Point)	Water Well Inventory
PITTSBURGH COAL		
PITTSBURGH_CROP_LINE2	-(Polygon)	Pittsburgh Coal Seam Crop Line
PITTSBURGH_DEEP_MINE	-(Polygon)	Extents of known Pittsburgh Coal Deep Mining
PITTSBURGH_STRIP_MINE	-(Polygon)	Extents of known Pittsburgh Coal Strip Deep Mining
PITTSBURGH_RESERVE		
RIVER_ACCESS_POINTSR1	-(Point)	Boat Ramp Locations
SAND_GRAVEL	-(Point)	Sand and Gravel Operations
SOILS	-(Polygon)	STATSGO Soils and MUID Database
SOILS_LAYER_PRIMARY	-(Polygon)	Top Layer of the Primary STATSGO soils
SWPA_MARINASR2	-(Point)	Marina Locations
UPPER_FREEPORT_COAL		
UPPER_FREEPORT_CROP_LINE	-(Polygon)	Upper Freeport Coal Seam Crop Line
UPPER_FREEPORT_DEEP_MINE	-(Polygon)	Extents of Known Upper Freeport Coal Deep Mining
UPPER_FREEPORT_STRIP_MINE	-(Polygon)	Extents of Known Upper Freeport Coal Strip Mining
UPPER_FREEPORT_RESERVE	-(Polygon)	Upper Freeport Coal Reserves (All)
ARCOAL	-(Polygon)	Armstrong Upper Freeport Coal
BECOAL	-(Polygon)	Beaver Upper Freeport Coal
WHITEWATER	-(Line)	Whitewater rafting/kayaking streams

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