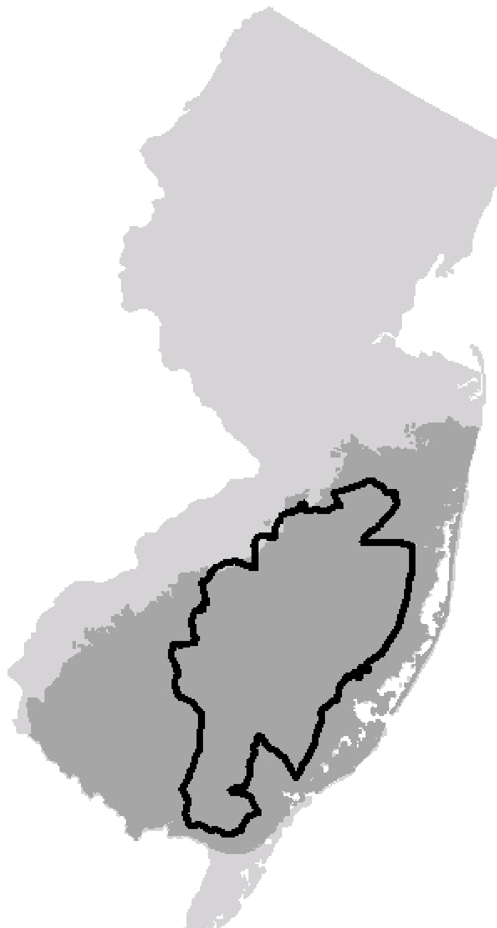
THE KIRKWOOD-COHANSEY PROJECT WORK PLAN



PINELANDS COMMISSION
AUGUST 11, 2003

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INTRODUCTION

New Jersey Public Law 2001, Chapter 165 directs the Pinelands Commission to assess and prepare a report on the key hydrologic and ecological information needed to determine how the current and future water-supply needs within the Pinelands area may be met while protecting the Kirkwood-Cohansey aquifer system and avoiding any adverse ecological impact on the Pinelands area. The aquifer assessment is to be implemented in cooperation with the New Jersey Department of Environmental Protection, Rutgers University, the United States Fish and Wildlife Service, and the United States Geological Survey. The legislation appropriated $5,500,000 from the Water Supply Fund for the preparation of the assessment by the Pinelands Commission.

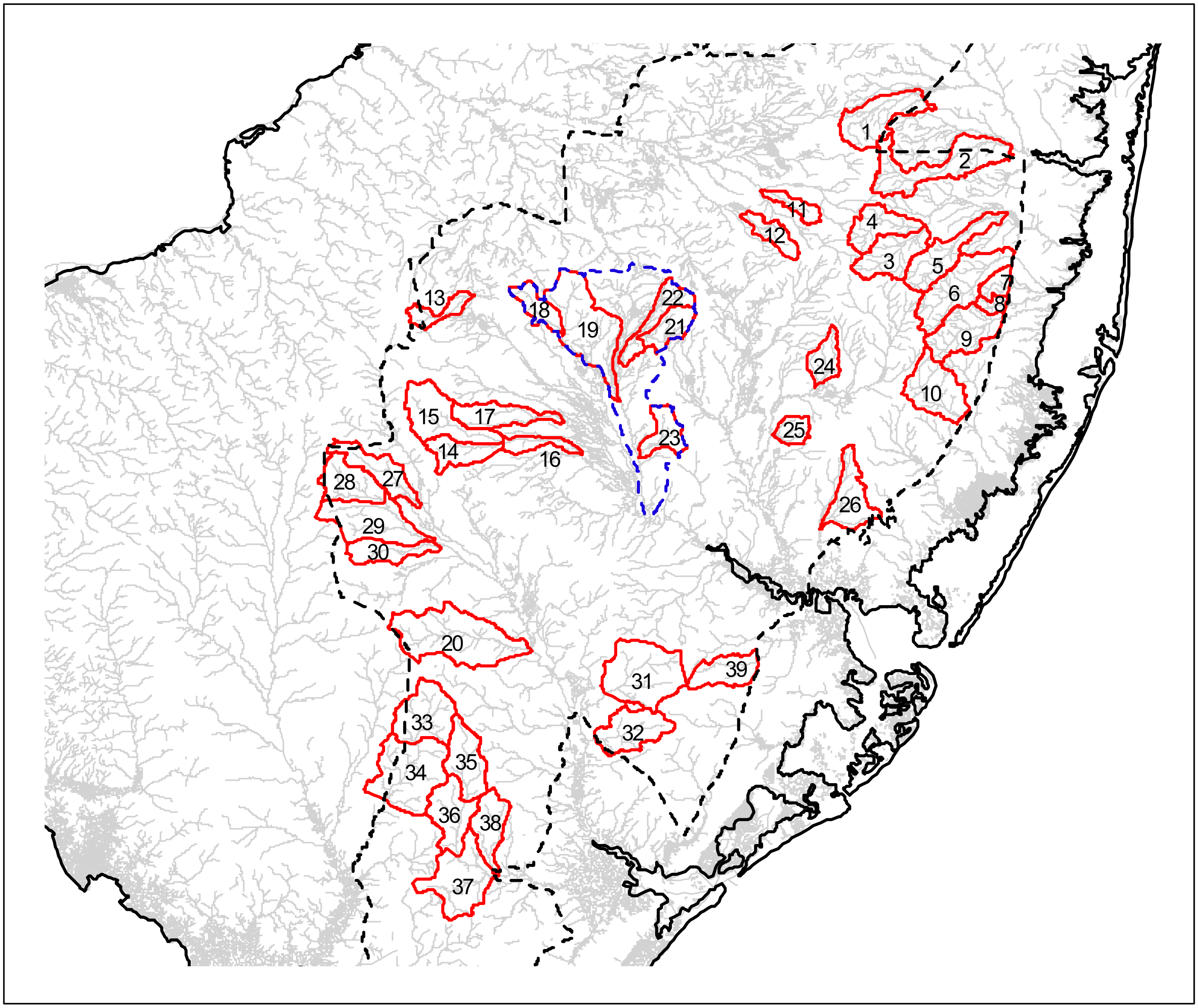
Scientists from the cooperating agencies and institutions met periodically to design a draft work plan for the Kirkwood-Cohansey Project. The draft was reviewed by a panel of scientists with expertise in the areas of research addressed in the work plan. The reviewers were Dr. John D. Aber, University of New Hampshire, Dr. Donald Siegel, Syracuse University, James P. Kurtenbach, U. S. Environmental Protection Agency, Dr. Curtis J. Richardson, Duke University, Dr. Charles T. Roman, National Park Service, and Ralph W. Tiner, U. S. Fish and Wildlife Service. Appropriate comments from the review were incorporated into this version of the work plan. The work plan addresses two major research questions. First, what are the probable hydrologic effects of groundwater diversions from the Kirkwood-Cohansey aquifer on stream flows and wetland water levels? Second, what are the probable ecological effects of induced streamflow and groundwater-level changes on aquatic and wetland communities?

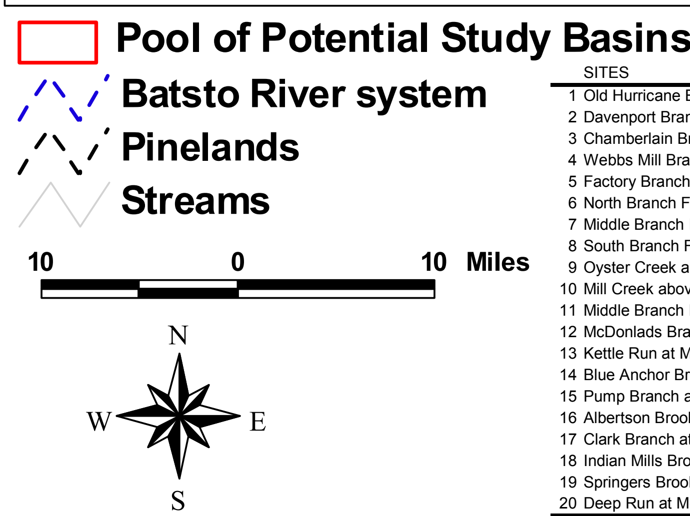
The proposed approach to answering these two related research questions includes several coordinated steps. As a first step, the work group completed an analysis to select potential study areas in the Pinelands area where the relationship between key hydrologic and ecological attributes will be characterized. A detailed study of these representative areas will provide the information needed to construct, calibrate, and verify numerical groundwater-flow models that can be used to predict the probable hydrologic changes resulting from groundwater diversions. Ecological models that relate community gradients and the distribution of individual species to natural and induced changes in stream flow or the depth, duration, and frequency of saturation and flooding are also proposed. The ecological models will be linked to the hydrologic models to evaluate the possible ecological effects of different water-diversion scenarios.

SELECTION OF STUDY AREAS

Several criteria were used to select potential study areas from a pool of 39 drainage basins located throughout the Pinelands (Figure 1). The goal of the study-area selection process was to choose study basins that represent a range of hydrologic, geological, land-cover, and ecological conditions. Key hydrologic criteria included aquifer thickness, drainage area, stream length, drainage density, past and current hydrologic monitoring and modeling, and existing and potential Kirkwood-Cohansey withdrawals. Land use, upland forest, wetlands, and soil type were among the major landscape features that were considered. Because relatively unrestricted access to uplands, wetlands, and streams will be necessary to effectively implement the project, the extent of public lands within potential study areas was given major consideration. Another selection criterion was the history of ecological research in each potential basin.

The McDonalds Branch, Pump Branch/Albertson Brook, and Morses Mill Stream basins were selected for a coordinated study of hydrology and wetland ecology. Additional wetland studies will be conducted in the Skit Branch and East Branch Bass River drainage basins. The Batsto River system will be the primary study area for stream-community investigations. This drainage includes a range of stream orders, water-quality conditions, and land-use characteristics. The East Branch Bass River





SITES		SITES	
1	Old Hurricane Brook above Horicon Lake	21	Skit Branch at Carranza Road
2	Davenport Branch at Mouth	22	Skit Branch at Mouth
3	Chamberlain Branch at Mouth	23	Penn Swamp Branch at Mouth
4	Webbs Mill Branch at Mouth	24	Papoose Branch at Mouth
5	Factory Branch at Mouth	25	Buck Run at Mouth
6	North Branch Forked River above Garden State Parkway	26	East Branch Bass River at Mouth
7	Middle Branch Forked River above Garden State Parkway	27	Sqaunkum Branch at Mouth
8	South Branch Forked River above Garden State Parkway	28	Hospitality Branch at Timber Lake
9	Oyster Creek above Garden State Parkway	29	Hospitality Brook above White Oak Branch
10	Mill Creek above Garden State Parkway	30	White Oak Branch at Mouth
11	Middle Branch Mount Misery Brook at Mouth	31	Babcock Creek at Route 322
12	McDonlads Branch below Reeves Bogs	32	Gravelly Run at Mouth
13	Kettle Run at Mouth	33	Manumuskin River above Old Mays Landing Road
14	Blue Anchor Brook at Mouth	34	Manumuskin River above Route 49
15	Pump Branch at Mouth	35	Tuckahoe River above Cumberland Road
16	Albertson Brook at Mouth	36	Tuckahoe River above Route 49 at Hunters Mill
17	Clark Branch at Mouth	37	Tuckahoe River at Route 49 at USGS Gage
18	Indian Mills Brook at Mouth	38	McNeals Branch at Mouth
19	Springers Brook at Mouth	39	Morses Mill Stream above Garden State Parkway
20	Deep Run at Mouth		

provides additional opportunities for stream-community and hydrologic studies as well. Intermittent-pond studies will be conducted within the proposed study areas and elsewhere.

With the exception of Morses Mill Stream, water-quality and stream discharge have been well documented in all the stream systems selected for study. Biological surveys have also been conducted in all six study area streams. McDonalds Branch, Skit Branch, and East Branch Bass River are undisturbed, acid-water streams dominated by public forest with excellent access. Pump Branch/Albertson Brook and Morses Mill Stream are characterized by elevated pH and stream communities that include nonnative species. Portions of Pump Branch/Albertson Brook basin are within Wharton State Forest, and Richard Stockton College is located within the Morses Mill Stream basin. Developed land and upland agricultural are a prominent feature of both basins, and several water supply wells are found in each. The Batsto River includes both degraded and undisturbed tributary systems and includes large tracts of public forest. McDonalds Branch, Skit Branch, and East Branch Bass River are characterized by a higher percentage of sandy soils compared to Pump Branch/Albertson Brook and Morses Mill Stream, where loamy sands or sandy loams are more common. The thickness of the Kirkwood-Cohansey ranges from 100-200 ft in the Skit Branch Basin to 200-400 ft in the East Branch Bass River basin.

WORK PLANS

The work plan is the product of numerous meetings and study-topic drafts prepared by project cooperators. Pinelands Commission staff was responsible for coordinating preparation of the final work plan with the goal of developing a comprehensive and coordinated program. The study topics are summarized in this section. Detailed work plans, which include the central questions to be addressed, major tasks to be completed, study details, and the lead and cooperating institutions and agencies that will conduct each study, follow this summary.

Hydrology (p. 8)

Variations in subsurface geology within the selected study areas exert a strong influence on hydrologic properties and function. The origin of the Cohansey Formation through deltaic deposition resulted in distinct zones with varying amounts and extensiveness of clay beds (Rhodehamel 1970, 1979). Variations in stream discharge are related in part to the clay content of the Cohansey or Kirkwood Formations. Shallow but extensive clay layers or ironstone deposits in the subsurface can exert considerable influence on aquifer recharge, streamflow runoff, stream-aquifer and wetlands-aquifer interconnections, perched water table conditions, and ecological environments.

The hydrologic investigation will examine the structure and function of the hydrologic system supporting Pinelands aquatic and wetland communities. It will focus on aspects of the hydrologic system that control groundwater and surface-water flow, depth to water in wetlands, and interactions between ground water, wetlands, and surface waters. A particular emphasis of this part of the project will be the development of models to quantitatively evaluate the response of the aquifer system in selected study areas to hydrologic stresses, including seasonal changes in recharge, drought, climatic change, and groundwater withdrawals. The goal is to develop hydrologic models that can be applied throughout the Pinelands area.

Hydrologic-system Structure and Function

As part of the proposed investigation, relations among hydrologic characteristics of the study areas, including the hydrogeologic framework, hydraulic properties, water-table configurations, and the various components of the hydrologic budget, will be characterized using existing data, field investigations, and physically based deterministic modeling. The central questions that will be addressed concern the hydrologic-system characteristics that influence ecologically important hydrologic regimes and the relations among critical components of the hydrologic budget. Evapotranspiration is an especially important component of the hydrologic budget for which information is presently limited.

Hydrologic controls

Relations between hydrologic-system characteristics and hydrologic-state variables, such as water levels in wetlands, rate of groundwater discharge to streams, and position of start-of-flow, will be characterized through field studies, aquifer tests, and modeling. Central questions to be addressed by this part of the project are how the aquifer system interacts with wetlands and streams and how these interactions are affected by pumping stresses.

Analytical capability

The evaluation of the hydrologic-system response to stresses on interacting hydrologic processes is best achieved through physically based deterministic modeling exercises. Pumping-induced changes in water-level and streamflow regimes will be simulated and evaluated using established hydrologic-modeling techniques. The results of hydrologic modeling will be integrated with models of the ecological response to hydrologic change.

Species and Community Indicators

The biological-indicator study topics focus on wetland and aquatic communities and associated species, emphasizing indicators that have been studied previously and that can be used to develop region-wide Pinelands ecosystem models. These indicators include wetland-forest communities and individual indicator species that comprise these communities, swamp pink (*Helonias bullata*), intermittent-pond vegetation, frogs and toads found in intermittent ponds, and stream fish and macroinvertebrate communities. Ecological processes such as nitrogen cycling, photosynthesis, and evapotranspiration are also addressed.

Wetland-forest Communities (p. 16)

The dominant Pinelands Area wetland-cover types are, in order of decreasing abundance, broad-leaved-deciduous forests (hardwood swamps), needle-leaved-evergreen forests (pitch pine lowlands), broad-leaved-deciduous scrub/shrub wetlands, Atlantic white cedar swamps, persistent emergent wetlands, and needle-leaved-evergreen scrub/shrub wetlands. Common shrubs found in these wetlands and along upland ecotones include scrub oak, lowbush blueberry, black huckleberry, sheep laurel, staggerbush, dangleberry, highbush blueberry, fetterbush, sweet pepperbush, swamp azalea, dwarf huckleberry, and leatherleaf. These indicator species and the vegetation types they comprise are distributed along complex-environmental gradients characterized by variations in water-table levels, soils, and disturbance history (Roman et al. 1985, Zampella et al. 1992, Ehrenfeld and Schneider 1991, Laidig and Zampella 1999). For example, scrub oak and lowbush blueberry are generally limited to the dry end of the vegetation continuum while dwarf huckleberry and leatherleaf are associated with the wet end. A typical upland to wetland community gradient is upland pine-scrub oak forest, dry pitch pine lowland, wet pitch pine lowland, and hardwood or cedar swamp.

Although the Pinelands landscape has been shaped by many factors, including disturbance associated with fire and timber harvesting, hydrologic regime is the major factor underlying the upland-to-wetland vegetation gradients that characterize the region. The central question that will be addressed as part of this study topic is how wetland-forest plant species and communities respond to changes in hydrology. Field studies will be conducted that relate the distribution of individual indicator species and forest types to variations in water level, soil moisture, texture and organic-matter content, and disturbance, among other factors. The results of these studies will be used to develop ordination and regression models for predicting possible shifts in species distributions and community composition that may result from simulated changes in water-table levels.

Swamp Pink (*Helonias bullata*) (p. 18)

Swamp pink (*Helonias bullata*) is a federally listed endangered wetland plant whose limited geographic distribution currently extends from New Jersey to Virginia. The majority of sites for this species are found on the coastal plain of southern New Jersey. Swamp pink is generally associated with water-saturated muck soils of hardwood swamps and Atlantic white cedar swamps. The species is considered highly sensitive to alterations in hydrology. Field studies will be conducted to determine what hydrologic regimes are associated with swamp pink colonies and to determine the distribution and abundance of swamp pink plants along hydrologic gradients. These results will be used to develop regression models describing potential changes in swamp pink distribution in response to modifications of the hydrologic regime.

Intermittent-pond Vegetation (p. 20)

Intermittent ponds that support open-water, emergent-herb, and shrub communities are found throughout the Pinelands. These shallow wetland depressions generally dry in the latter part of the growing season. Many support plant species that are rare in New Jersey. Annual and seasonal variations in water depth controls the distribution of plant species and vegetation zones found in intermittent ponds (Zampella and Laidig *in press*). The idealized zonation in these ponds can be characterized as concentric zones of pitch pine lowland forest, highbush blueberry, leatherleaf, sedges, emergent vegetation, and aquatic species. Field studies will be conducted to address questions similar to those dealing with wetland-forest communities. Appropriate site-specific and landscape-level ordination and regression models will also be developed to simulate potential changes in pond vegetation associated with altered hydrology.

Anuran-larval Development (p. 22)

Intermittent ponds are important breeding habitat for many native Pinelands anuran species, including Pine Barrens treefrogs, northern spring peepers, southern leopard frogs, and Fowler's toads, as well as species that are more typical of the peripheral Pinelands such as gray treefrogs and wood frogs (Bunnell and Zampella 1999, Zampella and Bunnell 2000). The successful recruitment of these species depends on the maintenance of adequate water levels for larval development. Altered hydrology may have a more pronounced effect on late-breeding species such as the Pine Barrens treefrog and gray treefrog because their transformation from larvae to adults occurs closer to the period when ponds usually dry. The central question to be addressed by the anuran-research component of the project is how larval development is related to intermittent-pond hydrology.

Stream Fish and Macroinvertebrates (p. 24)

Fourteen native-fish species may be found in Pinelands streams, and several nonnative species are associated with waters characterized by elevated pH (Hastings 1979, Hastings 1984, Zampella and Bunnell 1998). Although native fishes are adapted to the shallow and slow moving waters that typify the Pinelands, the conditions associated with small headwater streams may limit the distribution of some species and influence species richness. Studies conducted in the Mullica River basin (Zampella et al. 2001) indicate that species richness increases with basin area up to around 25 km^2, suggesting that smaller streams support fewer species. The native eastern mudminnow and banded sunfish were generally the most common fish encountered in the smaller streams within the basin. Lower species richness in headwater streams may be related to the intermittent nature of these habitats or to low dissolved oxygen concentrations associated with low flows.

Aquatic macroinvertebrates are a dominant component of the diet of most native Pinelands fish species. Current, substrate, and oxygen are among the most important factors influencing the distribution and abundance of stream macroinvertebrates. These three factors are interrelated, with current partly determining both sediment type and dissolved oxygen levels.

The stream-community study will address two related questions. First, how do stream fish and macroinvertebrate assemblages respond to variations in streamflow regimes? Second, how do site-specific habitat variables, such as temperature, dissolved oxygen, bank cover, stream vegetation, sediments, and channel morphology, interact with stream-discharge to effect fish and macroinvertebrate composition? The results of the field studies will be used to develop appropriate ordination and regression models relating community and species gradients to natural and induced changes in the streamflow regimes.

Ecological-process Indicators

Nitrogen (p. 26)

Limiting nitrogen loading to Pinelands surface waters and ground waters is a major goal of the Pinelands Comprehensive Management Plan. Variations in nitrogen content and dynamics (e.g., mineralization and nitrification) in forest soils are frequently associated with soil moisture. This study, which includes laboratory and field components, will assess whether unsaturated conditions associated with lowered water-table levels promote increased nitrogen mineralization and nitrification, resulting in pulses of mineral nitrogen to wetland systems.

Physiological Indicators (p. 27)

In plants, stress due to marginal-growth conditions associated with altered hydrologic regime may be reflected by physiological responses long before death or obvious growth reductions become apparent. Because many of the indicator-plant species to be studied are woody shrubs, their response to alterations in water regime may be slow. It can be expected that wetland-adapted plants will experience drought stress under hydrological conditions that are optimal for upland plants. Moreover, differences in tolerance to both dry soils and wet soils may eventually drive changes in community composition. Physiological measurements can serve as an indicator of the stresses that may eventually lead to changes in community composition.

Transpiration and photosynthesis are two physiological processes that may be affected by water availability. In this study, the balance between the ability of the plant to take up water and the evaporative demand on water at the leaf surface will be measured. When evaporative demand is greater than the root system can supply, the plant is under water stress, which limits growth and survival. Carbon dioxide uptake, which is widely used as a measure of photosynthetic capacity and is a good indicator of the potential of the plant to survive and grow, will also be measured. Comparison of values across the hydrologic gradient may indicate at which point each species experiences stress due to either drought or induced water-table changes.

Landscape Models (p. 28)

The ordination and regression models developed as part of the species, community, and ecosystem-process field studies will be translated into GIS-based models that will be used to estimate the effects of induced hydrologic changes across the landscape of the study areas. The GIS-based species and community gradient models will be used to assess the landscape-scale distribution of community types and individual species responses to changes in hydrologic regime. The ecosystem-process landscape models will be used to estimate water stress and photosynthesis under different hydrologic-regime scenarios. The goal is to develop models that can be applied throughout the Pinelands area.

Build-out and Water-demand (p. 31)

Knowledge of current and future water-supply demands is necessary to evaluate the long-term sustainability of the Pinelands ecosystem. This information will be obtained by completing a build-out and water-demand analysis. The central questions to be addressed concern the rate at which population and dwelling units will be expected to grow within Pinelands, predicted development patterns at build-out, and current and future water-supply demands?

Data Management and Data-analysis Coordination (p. 34)

A project-wide data management system will provide a centrally administered long-term repository for Kirkwood-Cohansey Project data that can be served via Internet access to study team members and the public. Data sharing needs among researchers, data-management objectives, data types, and linkages between data types will all be identified and incorporated in the database design. Data products, including tables, maps, GIS raster and vector data sets, etc., will need to be made available for efficient access. Data analysis methods used to develop ordination and regression models resulting from the different ecological studies must also be coordinated to ensure consistency among the studies and compatibility with the landscape-level models.

Public Information and Final Kirkwood-Cohansey Assessment (p. 35)

Several other tasks will be completed during the Kirkwood-Cohansey Project. A public information program will be developed to inform cooperators and the public about the purpose, approach, and progress of the project. The results of the individual studies will be assembled to produce a comprehensive project report.

HYDROLOGY (USGS WITH DEP AND RUTGERS)

Central Questions

1. **What are the hydrologic-system controls on hydrologic regimes?**

2. **What are the relations among components of the hydrologic budget?**

3. **How do the aquifer, wetlands, and streams interact hydrologically and how are these relations affected by pumping stress?**

4. **How are wetland water levels and stream flows affected by pumping stress?**

5. **What is the relative contribution of various land cover/natural-vegetation community types to the regional water demand through the process of evapotranspiration (ET).**

6. **How can evapotranspiration (ET) be estimated at the watershed scale?**

Tasks

Task 1. Characterize the hydrogeologic framework and prepare a hydrostratigraphic model of each study area.

Task 2. Characterize water-level regimes in support of hydrologic and ecological tasks, ensuring that water-level monitoring efforts are coordinated and optimized.

Task 3. Characterize stream flows in support of hydrologic and ecological tasks, ensuring that streamflow-monitoring efforts are coordinated and optimized.

Task 4. Prepare detailed topographic and water-table maps of the study areas and characterize groundwater-flow patterns in coordination with ecological-study efforts.

Task 5. Monitor evapotranspiration in the field and use the ET measurements to develop a method for determining ET at the watershed scale.

Task 6. Characterize wetland/aquifer interactions under unstressed and stressed (pumping) conditions in the study areas.

Task 7. Develop a water budget for each study area, including the evaluation of temporal variations in budget components and the determination of average annual-water budgets.

Task 8. Develop, calibrate, and verify hydrologic models.

Task 9. Apply hydrologic models and interpret the results.

Task 10. Document, present, and publish the hydrologic data, analyses, and interpretations.

Study Details

Hydrogeologic Framework of the Study Areas

1. Using available information, develop a geodatabase for existing borehole information and produce

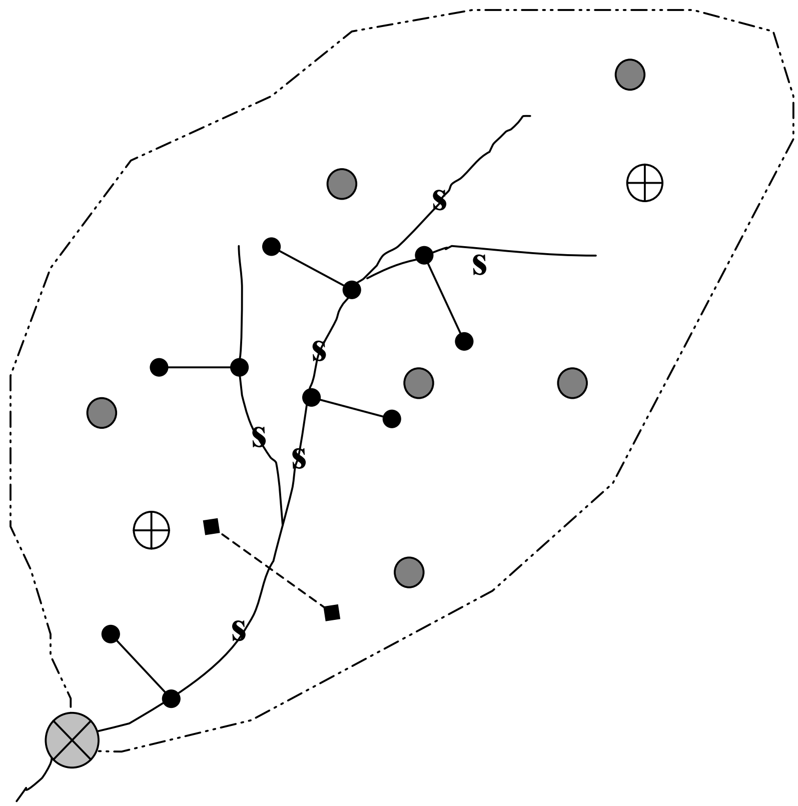
maps showing the relevant attributes, such as the altitude and thickness of clay layers and the percentage of sand in cuttings, of existing borehole data sets.

2. Compile and evaluate information on surficial geology, stratigraphy, aquifer and confining unit properties, and well construction and performance.
3. Based on an evaluation of available information, conduct additional borehole and surface geophysical surveys and testing (estimated number of boreholes and wells are shown in parentheses).
   a. Characterize the lithology and composition of borehole cuttings (15).
   b. Conduct borehole geophysical surveys, including electric logging and gamma logging in all boreholes (Figure 2).
   c. Conduct surface geophysical surveys including ground-penetrating radar (GPR) surveys, electrical-resistivity surveys, seismic-reflection surveys, and electromagnetic (EM) profiling and sounding.
   d. Conduct slug tests on all completed observation wells (54 wells[1]) to provide information on aquifer hydraulic properties.
4. Interpret and integrate information on hydrogeologic framework and hydraulic properties and prepare a hydrostratigraphic model for each study area, including:
   a. cross sections across study areas,
   b. maps of the areal extent and thickness of major water bearing units and confining units (or zones with a high density of smaller clay/silt lenses, if present), and
   c. maps of zones of contrasting lithology/hydraulic conductivity within major units.
5. Products. A hydrostratigraphic model and supporting data for each study area and a report describing study methods, results, and interpretations.

Water-level Regimes

1. Compile and evaluate available information on groundwater-level monitoring in study areas.
2. Locate wells from previous investigations using a GPS.
3. In each study area, establish two well nests, situated for optimal spatial distribution and coordination of other tasks (existing observation wells will be used where possible, e.g., one 120' well is available in Pump Branch Basin and two shallow wells are available in McDonalds Branch Basin). Each well nests will include:
   a. One deep 4-in well (approx. depth 175-250 ft).
   b. One intermediate-depth 4-in well (approx. depth 100-150 ft).
   c. One shallow 1-in driven well (approximately depth 25-40 ft).
4. Conduct borehole geophysical surveys, including electric logging and gamma logging in the boreholes of each drilled well and place screens in the identified water-bearing strata.
5. In each study area, establish hydrologic transects through a representative wetland area, consisting of a series of three shallow (approximately 5 ft) and three deep (approximately 20 ft) piezometers.
6. Instrument each observation well with a pressure transducer and data logger, which will record water levels at an hourly interval. Download and service data loggers at approximately 6-week intervals.
7. Using the Geoprobe® direct push technique, drive an average of five additional 1-in upland observation wells per study area (completed well depths will be approximately 15-35 ft). Measure water levels in these wells manually during synoptic surveys.
8. Secure permission to measure water levels from owners of wells that were measured during previous surficial-aquifer studies. Identify other existing wells as needed and secure permission to measure water levels.

[1] The 54 wells include the following for each of three study areas: an average of five Geoprobe® wells for synoptic surveys, three deep piezometers, three shallow piezometers, two nests of three drilled observation wells, and one drilled high-capacity well for pumping.



Continuous streamflow gaging station (1)

Basin monitoring well nest with continuous water level instrumentation (2)
1 shallow well ~ 5-12 m depth, 1” diameter
1 intermediate borehole and well ~ 40-50 m depth, 4” diameter
1 deep borehole and well; ~70-75 m depth, 4” diameter

6 uplands observation wells ~5-12 m depth

S 6 streamflow seepage run sites

Hydrologic gradient transect (5) which may coincide with ecological transect
3 shallow wells ~1-2 m depth, 1 staff gage, surface geophysical surveys

Hydrologic stress test setup (1):
1 borehole/pumping well ~15-20 m depth, 6” diameter, 25’ screen
3 shallow observations wells ~1-2 m depth
3 deeper observations wells ~5-8 m depth
1 staff gage, surface geophysical surveys

Figure 2. Example study-area configuration for hydrologic field investigation.

9. Water levels in observation wells, other available wells, and piezometers (approximately 120) will be measured twice synoptically, along with approximately 40 stream stage altitudes measured at bridge crossings and other stream access points.
10. Process well construction and water-level data and enter the data into the Kirkwood-Cohansey Project and the USGS National Water Information System databases.
11. Products**.** A water-level monitoring network, water-level database, and a methods report.

Stream Flows

1. Compile and evaluate available information on stream-gaging in study areas.
2. Establish and maintain a continuous streamflow-gaging station at a downstream end of each study-area stream at locations where previous flow measurements are available (one station in the Morses Mill Stream watershed and two stations in the Pump Branch/Albertson Brook watershed).
3. Establish 15 additional staff gages (5 per study basin) as part of the hydrologic-gradient transects and aquatic-community assessments and record stream stage approximately monthly and during two seepage runs.
4. Conduct stream-seepage runs concurrently with the synoptic water-level survey at six sites in each study area and again during a contrasting flow condition and use the results to characterize the distribution of flow gain or loss across the study areas under base-flow conditions.
5. Establish four additional staff gages in the Batsto River system for the aquatic community assessment, record stream stage approximately monthly, and complete forty-eight streamflow measurements (12 per gaging site) to provide a basis for correlating stream stage with discharge.
6. Identify start-of-flow locations by surveying headwater tributaries (approximately 25 among the three study areas) concurrently with the water-level survey and seepage run. Accessible headwaters tributaries will be walked and start of flow locations will be mapped using a GPS. Start of flow information will be mapped and used in producing water-table maps and in calibrating groundwater flow models.
7. Develop rating curves for aquatic community assessment sites.
8. Process streamflow data and enter the data into the Kirkwood-Cohansey Project and the USGS National Water Information System databases.
9. Products**.** A stream discharge monitoring network, streamflow database, and a methods report.

Topographic and Water-table Maps and Groundwater-flow Patterns

1. Compile and evaluate available information on topography and water-table levels for each study area.
2. Prepare water-table maps and depth-to-water maps using existing remotely sensed data, 10-m DEMs, ground-penetrating radar (GPR) surveys (Hydrology Task 1), and synoptic water-level surveys (Hydrology Task 2).
3. Describe flow patterns from uplands to stream-discharge areas by preparing interpretive tools such as flow net diagrams in section view through the hydrologic gradient transects that include observation wells at different depths.
4. Products. Water-table maps, depth to water maps, flow-net diagrams, and a report describing study methods, results, and interpretations.

Evapotranspiration (ET)[2]

1. Directly measure ET at key sites in the field using an instrumented tower extending above the forest canopy.
   a. Select monitoring sites so the measured ET within the tower "footprint" can be partitioned into components characteristic of two different adjacent vegetative types (Sumner 2001).
   b. Monitor ET using an energy-budget variant of the eddy covariance method (Sumner 1996, Tanner and Greene 1989).
   c. Determine daily ET by closing the energy-balance equation, using direct measurements for the determination of the ratio of sensible heat flux to latent heat flux (Bowen ratio).
2. Determine ET at the vegetation-type scale.
   a. Measure vegetation, leaf-area index (LAI), and stomatal conductance in forest plots representing a range of vegetation types. Include plots within the tower "footprint" and plots used for the wetland-forest gradient study.
   b. Use the LAI data to develop an algorithm to estimate LAI at watershed scale based on a remotely sensed Normalized Difference Vegetation Index (NDVI).
   c. Measure sap-flow rates of individual plants of different species within the tower "footprint." The sap flow rate will allow for the discrimination between transpiration and evaporation processes and the calibration of soil evaporation and plant transpiration independently in the process-based ET model.
   d. Measure and observe soil texture properties at forest plots to determine soil-water-holding capacity and permanent-wilting point.
3. Develop a method for determining ET at the watershed scale.
   a. Develop a 3-layer net radiation canopy ET model for the forest plots within the tower "footprint." This model will be extended throughout the ET tower footprint area and calibrated against the tower data.
   b. Develop, calibrate, and verify a spatial distribution model of ET based on the direct tower measurements and 3-layer canopy radiation-transfer model to extend the understanding of ET to the scale of the study basins.
4. Products. A spatial distribution model of ET and watershed-level estimates of ET.

Wetland/Aquifer Interactions

1. Using methods illustrated by Modica (1998), characterize wetland/aquifer interactions under unstressed conditions by evaluating head gradients across hydrologic transects and stream stage to determine water-level fluctuations, hydroperiod, groundwater seepage, and flow patterns.
2. Evaluate interactions under pumping stress conditions by conducting an aquifer test in each study area in the vicinity of the hydrologic transects.
   a. The pumping well will be situated in an upland area that is adjacent to a wetland area and stream, within 2000 m of a downstream stream-gaging station, and positioned as an extension of the hydrologic stress test setup (Figure 2).
   b. The well will be pumped at a rate on the order of hundreds of gallons per minute for a period of 1 – 2 weeks.
   c. Pumped water will be routed away from the test site.
   d. Water levels will be recorded continuously using pressure transducers in the observation wells distributed along the hydrologic transect.
3. Evaluate water-level responses and induced head differences among stream stage, wetlands, and the underlying aquifer to determine hydraulic properties and further refine the conceptual model of the wetlands-aquifer interface. This evaluation will be facilitated by modeling site-specific conditions. Fine-grid site-scale flow models embedded in watershed-scale flow models will be developed for

[2] The details for the evapotranspiration component have not been finalized.

each test site using telescopic mesh refinement techniques (Leake and Claar 1999). The site-specific response to pumping will be simulated using the fine-grid model, providing an improved understanding of the controls on the hydrologic response to pumping at the site. By repeating this detailed evaluation at test sites in three contrasting study areas, a firm understanding of the wetland response to pumping stress will be achieved

4. Products. A report describing the study methods, results, and interpretations.

Water Budgets

1. Quantify and balance the major water-budget components (precipitation, ET, surface runoff, withdrawals, groundwater discharge to streams, changes in storage, and recharge) for each study area.
   a. Determine both a land-surface and a groundwater budget for each study area.
   b. Determine precipitation from meteorological stations in each study area and from existing nearby stations using Theissen polygon analysis or other spatial-interpolation techniques.
   c. Determine ET using measured ET and output from regional ET models (Hydrology Task 5).
   d. Determine surface runoff from continuous streamflow data using hydrograph-separation techniques.
   e. Obtain groundwater withdrawal information from the NJDEP Bureau of Water Allocation or directly from water purveyors.
   f. Determine changes in storage from measured water-level fluctuations in observation wells and storage coefficients determined from aquifer tests.
   g. Estimate recharge as a residual in both the land-surface and groundwater budget analyses.
2. Determine monthly variations in water-budget components for periods of data collection and estimate monthly variations representative of a typical seasonal cycle for use in model simulations (i.e., a representative, 12-month period based on average seasonal conditions).
3. Products. A report describing the study methods, results, and interpretations.

Development, Calibration, and Verification of Hydrologic Models

1. Using available information on geology, hydrology, wetlands, and topography, formulate a conceptual model for each study area. The conceptual models will identify all the critical hydrologic characteristics and processes (i.e., significant confining layers, known zones of high or low aquifer permeability, and the expected relation between streams, wetlands, and aquifer) to be represented in hydrologic models.
2. Describe the conceptual models using conceptual figures in section view and an approximation of the hydrologic budget.
3. Use the conceptual models to guide the design of a detailed numerical model for each study area.
   a. The proposed model code is MODFLOW-2000 (Harbaugh et al. 2000), for which modules exist for representation of the interactions between aquifer, streams, lakes, and wetlands.
   b. The model domain will be discretized laterally such that hydraulic gradients in critical wetland/upland transition zones are adequately represented. Lateral discretization will provide 10-m resolution in wetlands/transition areas and a maximum 30-m resolution in upland areas.
4. The model domain will also be discretized vertically such that significant confining layers and significant high or low permeability layers are represented as individual units, rather than as lumped aquifer/confining unit blocks.
5. Use information on the hydrogeologic framework from previous investigations (maps, lithologic descriptions, drillers' logs) and field investigations described earlier (lithologic logs, borehole and surface geophysics) to specify the extents and geometries of modeled hydrologic units.
6. Use information on hydraulic properties obtained from previous hydrologic investigations (aquifer test results, lithologic descriptions, drillers' logs) and Hydrology Task 1 (slug test results, well performance tests, borehole and surface geophysics, hydraulic gradient analysis) to define initial estimates of the hydraulic properties of modeled hydrologic units.

7. Define model boundaries.
    a. Use hydrologic features to define individual study-area model domains. One objective of defining lateral boundaries is to ensure that simulated hydrologic effects are not constrained by assumptions about the position of groundwater divides. A common practice for addressing this issue is to extend the model domain beyond the study area watershed to an adjacent surface-water body.
    b. Define the lower boundary of the model domain as the bottom of the Kirkwood-Cohansey aquifer, as mapped by Zapecza (1989), and modified as indicated by local borehole information.
    c. Specify recharge boundaries across the top of the model domain and include aquifer recharge resulting from processes such as infiltrating precipitation, leakage from streams, irrigation return flow, and subsurface flow from adjacent areas.
    d. Define discharge boundaries as groundwater discharge to wetlands, streams, and impoundments, pumping wells, leakage to underlying aquifers, and subsurface flow to adjacent areas.
    e. Determine areal recharge using a land-surface water balance approach and incorporating the results of ET monitoring. If ET rates are found to be dependent upon depth to water in wetlands and wetland/upland transition areas, a model discharge boundary will be specified to account for this relation. This boundary can be specified as a linear head-dependent function with a specified extinction depth (Harbaugh et al. 2000) or by using some other specified head-dependent function (Banta 2000).
8. Calibrate models by adjusting model parameter values while comparing simulated heads and flows with counterpart field measurements and other interpretations that utilize field measurements. Model calibration will include the definition of calibration indices, calibration criteria, and approaches for evaluating calibration.
    a. Calibration indices are measurable hydrologic features such as hydraulic head as measured in a well, the start of flow of a first order stream, and stream baseflow as measured at a specific location. Baseflow for continuous-record gaging stations will be determined using hydrograph-separation techniques, such as the RORA method described by Rutledge (1998) and the HYSEP method described by Sloto and Crouse (1996). Baseflow for partial-record stations will be estimated by correlating low-flow discharge with concurrent discharge at continuous gaging stations. Correlations will be developed by using the Maintenance of Variance Extention, Type 1 (MOVE.1) method, which makes use of geometric means to eliminate bias of ordinary-least-squares-regression (Hirsch 1982).
    b. Calibration criteria are the history-matching benchmarks by which model output is evaluated.
    c. Approaches for achieving and evaluating model calibration include the application of measures of goodness-of-fit, examination of spatial and temporal bias, and systematic analysis of model sensitivity.
    d. Models will be calibrated to both steady-state and transient-state flow conditions. Initial calibration will involve matching simulated steady-state outputs with annual average head and base flow conditions. Subsequent transient-model calibration will involve matching simulated monthly outputs with observed monthly heads and base flows, and the response to controlled stress tests.
    e. Calibration criteria will reflect a need for higher simulation accuracy in wetland/transition areas than in uplands. The planned head residual criteria are 0.15 m in wetlands/transition areas and 0.6 m in upland areas over all simulated flow conditions. The planned stream baseflow residual criterion is five percent or 0.015 m^3/s over all simulated flow conditions, whichever is greater.
9. Evaluate model representations of contrasting hydrologic conditions by using independent data sets representing conditions different from those simulated as part of model calibration.
10. Products. Calibrated and verified groundwater-flow models and a report documenting the methods.

Application of Hydrologic Models and Interpretation of Model Results

1. Use the build-out and water-demand assessments and hypothetical demands to prepare hydrologic-model input-data sets to simulate the effect of various pumping scenarios on each study area.
   a. Several scenarios for each area will be formulated.
   b. Demands will be specified with respect to the location, rate, and time of extraction.
   c. A corresponding set of hydrologic input parameters, including recharge, that represent both normal and drought conditions will be developed.
2. Evaluate the water demand scenarios using the hydrologic models.
   a. The model output represents the hydrologic system as water level and water budget information throughout specified time periods. Evaluation of scenarios will focus on simulated changes in these hydrologic features.
   b. Using a GIS, the model-output information will be plotted as potentiometric surface or water table maps, drawdown maps, and hydrologic budget changes.
   c. Simulated water-level changes will be reported in a minimum-increment of 0.15 m and simulated streamflow changes will be reported in a minimum increment of 0.015 m^3/s.
   d. The results will be used to identify resource-management issues and concerns, focusing on the planned growth and hypothetical withdrawals within the areas of the three study basins.
   e. Additional scenarios will examine the sensitivity of well location, well depth, and well operation strategies on hydrologic responses to withdrawals.
3. Integrate the hydrologic-model results with the ecological landscape models in order to estimate the ecological effects driven by simulated hydrologic changes. An iterative process may be devised in order to test the sensitivity of this model integration approach.
4. Test scenarios to examine the sensitivity of various hydrologic processes to variations expected throughout the Pinelands. In addition to testing future water demand scenarios, the hydrologic models provide a useful tool for evaluating and understanding the workings of hydrologic systems. These evaluations will provide useful information to enhance the understanding of Pinelands hydrology.
5. Develop various techniques to facilitate the transfer of information learned about the three study areas to other parts of the Pinelands. Techniques will include the use of numerical-model analysis in the calibration of statistical relationships, the use and calibration of analytical hydrologic models, and the development of heuristic models. These models will be used to provide information for the landscape-scale ecological models developed in another phase of this study.
6. Products. A report describing study methods, results (including maps, tables, GIS data sets of simulated changes in wetlands water levels, start of flow, and streamflow linked to ecological landscape models), and interpretations.

Documentation, presentation, and publication of hydrologic data, analyses, and interpretations

The overall results of data collection, model development, model calibration, and analysis of scenarios will be summarized in intermediate products and in a comprehensive USGS Water Resources Investigations Report.

WETLAND-FOREST COMMUNITY GRADIENTS (PC)

Central Questions

1. **How do wetland-forest plant species respond to changes in water regime (e.g., seasonal water-level patterns, mean and extreme water levels)?**

2. **How do wetland-forest plant communities and the boundaries between communities respond to changes in water regime (e.g., seasonal water-level patterns, mean and extreme water levels)?**

Tasks

Task 1. Select representative transitional-upland and wetland sites in each study area.

Task 2. Conduct field characterization of transitional-upland and wetland communities.

Task 3. Monitor relevant environmental factors, including water levels, soil texture, soil organic matter, soil moisture, and site history. Coordinate water-level monitoring with the USGS hydrologic monitoring efforts.

Task 4. Develop ordination and regression models relating wetland-forest community gradients and the distribution of indicator species to natural and induced changes in the depth, duration, and frequency of saturation and flooding.

Study Details

Study-area Selection

1. Use NJDEP Freshwater Wetlands data, aerial photographs, and field surveys to select forest plots comprising representative wetland types that typify upland to wetland gradients in each study area. Wetland types and the number of plots will vary depending on study-basin characteristics. A total of 200-250 forest plots will be established in the five study areas. The objective is to characterize the full range of wetlands in the Pinelands and reflect the overall composition of the region. Vegetation types will include:

Dominant Cover	**Class**
Upland pine-oak or oak-pine forest (upland)	-------
Dry pitch pine lowland	PFO4-dry
Wet pitch pine lowland	PFO4-wet
Wet pitch pine lowland with an open canopy and coppice growth[3]	PFO4-wetx
Dry pitch pine lowland with an open canopy and coppice growth[3]	PFO4-dryx
Wet pitch pine lowland with hardwoods	PFO4/1
Hardwood swamp	PFO1
Hardwood swamp with pitch pine	PFO1/4
Atlantic white cedar swamp	PFO8 or PFO8/1
Shrub wetland (deciduous or evergreen)	PSS1 or PSS4

[3] Representing areas severely disturbed by past wildfires.

Field Characterization of Transitional-upland and Wetland Communities

1. Establish 10 x 10-m plots representing the range of dominant vegetation types found in each study area. A $100m^2$ plot is adequate to characterize understory vegetation (Mueller-Dombois and Ellenberg, 1974). Due to the patchiness of Pinelands vegetation, it is difficult to establish larger plots consisting of understory vegetation typifying a particular hydrologic regime. Plots will be selected systematically based on species composition and position relative to adjacent vegetation types.
2. Measure cover (abundance) of all canopy and understory species along randomly placed transects oriented perpendicular to the topographic gradient.
3. Complete presence/absence inventory for all species.
4. Measure shrub-height profiles along each transect.
5. Measure the diameter at breast height (dbh) of all trees > 2.5 cm in diameter.

Environmental Measurements

1. Install a continuous-record reference well at an upland site, a lowland site (mineral soils), and a swamp site (organic soil) in each study area. Coordinate water-level monitoring with the USGS hydrologic-monitoring efforts.
2. Install partial-record monitoring wells within each forest plot. Monitor each well at a frequency sufficient to estimate the continuous record using the reference wells (Zampella et al. 2001).
3. In each plot, complete soil color and texture descriptions to a depth of 50 cm.
4. In each organic-soil plot, complete three measurements of peat/muck depth to the underlying sand.
5. In each plot, collect and pool three 10-cm surface-soil samples for percentage organic-matter and pH analysis. The 10-cm soil depth represents the zone of highest tree and shrub root density in sandy soils of the Lakewood catena (Laycock 1967, Zampella 1994).
6. During the growing season, use gravimetric methods or time-domain reflectometry (TDR) to measure soil moisture in the upper 10 cm of soil. Complete these measurements monthly in at least 30 plots representing the range of soil conditions. Relate soil moisture to percentage organic matter and water level to estimate soil moisture at all sites.
7. Complete environmental measurement over a period of at least two years.
8. Record any evidence of recent fires.

Models

1. Develop and validate ordination and regression models relating wetland-forest community gradients and the distribution of indicator species to natural and induced changes in the depth, duration, and frequency of saturation and flooding.
2. Coordinate model development with other cooperators.

Products

A report describing study methods, results, and interpretations, ordination and regression models, and supporting data entered in the Kirkwood-Cohansey Project database.

SWAMP PINK *(HELONIAS BULLATA)* (USFWS)

Central Questions

1. **What hydrologic regimes (e.g., seasonal water-level patterns, mean and extreme water levels) are associated with *Helonias bullata* colonies?**

2. **How does *Helonias bullata* respond to natural and simulated changes in the depth, duration, and frequency of saturation and flooding?**

Tasks

Task 1. Select three *Helonias bullata* sites in the Pinelands.

Task 2. Conduct field studies to determine the abundance and spatial distribution of *Helonias bullata* along hydrologic gradients at each site.

Task 3. Monitor relevant environmental factors, including water levels, peat depth, topography, and shading. Coordinate water-level monitoring with the USGS hydrologic-monitoring efforts.

Task 4. Develop regression models relating *Helonias bullata* distribution to variations in the depth, duration, and frequency of saturation and flooding.

Study Details

Study-area Selection

1. Use USFWS data or NJDEP Natural Heritage Database to select three *Helonias bullata* sites in the Pinelands.
2. Select sites where characterization of the hydrologic gradient can be accomplished with a reasonable amount of effort (i.e., avoid broad wetlands).

Field Characterization of *Helonias bullata* Communities

1. Establish nine transects to map the distribution of *Helonias bullata* rosettes through the limits of the species' distribution at each site. Transects should be placed systematically through the center of the population, be spaced no more than five meters apart, and be parallel to the hydrologic gradient. If a stream is present, it will be used as the arbitrary lower boundary of the colony.
2. The total length of each transect should be a maximum of 15 m. If necessary, the transect can be divided into sections (e.g., three five-meter sections) to cover the full length of the colony. Endpoints of each transect should be staked and recorded with a mapping-grade global positioning system.
3. Along each transect, record the point location of all rosettes and count flowering stalks and seedlings on the intercepted rosettes. Counts should be conducted from mid-April to mid-May.
4. Use the line intercept method to record *Helonias bullata* rosette cover, shrub cover (by species), and ground cover leaf/needle litter, *Sphagnum*, other mosses, herbs, and exposed-tree roots) along each transect.
5. Using a densitometer and the line-intercept method, measure tree-canopy cover by species along each transect.

Environmental Measurements

1. Use measures of relative elevation, based on an arbitrary datum, and water levels to estimate the hydrologic gradient along each transect.
   a. Install a single continuous-record well at the center of one transect and install a single shallow partial-record well at the center of the remaining transects.
   b. Over a two-year period, conduct monthly depth-to-water-level measurements at the partial-record wells under base-flow (fair weather) conditions and during wet and dry seasons.
   c. Using a transit and an arbitrary reference point, measure relative elevations at one-half meter intervals along each transect. All elevations and water levels may then be rescaled relative to the lowest point on the transect as described by Laidig and Zampella (1999).
2. At 1-m intervals along each transect, measure peat/muck thickness to a depth of 1 m.
3. During the growing season, use gravimetric methods or time-domain reflectometry (TDR) to measure rooting-zone soil moisture monthly at the center of one transect.

Models

1. Use regression to develop and validate models relating the *Helonias bullata* gradient to natural and simulated changes in the depth, duration, and frequency of saturation and flooding.
2. Coordinate model development with other cooperators

Products

A report describing study methods, results, and interpretations, regression models, and supporting data entered in the Kirkwood-Cohansey Project database.

INTERMITTENT POND VEGETATION (PC WITH DEP)[4]

Central Questions

1. **How do intermittent-pond plant species respond to changes in water regime (e.g., seasonal water-level patterns, mean and extreme water levels)?**

2. **How do intermittent-pond plant communities and characteristic plant zones respond to changes in water regime (e.g., seasonal water-level patterns, mean and extreme water levels)?**

Tasks

Task 1. Conduct field characterization of intermittent-pond plant-species gradients.

Task 2. Monitor relevant environmental factors, including water levels, pond morphometry, water chemistry, soil texture, soil organic matter, adjacent forest type, and site history. Coordinate activities with the USGS hydrologic-monitoring efforts.

Task 3. Develop ordination and regression models relating intermittent-pond plant-species gradients to natural and induced changes in the depth, duration, and frequency of saturation and flooding.

Study Details

Intermittent-pond Vegetation

1. Describe the vegetation of intermittent Pinelands ponds.
2. Describe the major environmental factors associated with intermittent-pond vegetation patterns, emphasizing hydrologic regime.
3. Describe the major factors associated with the distribution of individual intermittent-pond plant species, emphasizing hydrologic regime.
4. Identify hydrologic-regime indicator species.

Selection of Study Ponds

1. Select 10-15 study sites from a pool including ponds identified by the Office of Natural Lands Management, 14 sites previously established by the Commission, and sites within the hydrologic study areas, with priority given to the latter.
2. Place priority on sites that are suitable for anuran studies.

Pond-vegetation Surveys

1. In early and late summer, map vegetation within each pond and an adjacent 2-m buffer with a global positioning system (GPS) and estimate abundance using cover ranks.

[4] This study will be conducted in cooperation with the NJDEP Office of Natural Lands Management. The ONLM is initiating a project with the primary objective of classifying natural coastal plain pond communities in the Inner and Outer Coastal Plain of New Jersey. The pool of potential study sites will include ponds mapped by the ONLM, 14 ponds that the Commission has monitored for several years, and sites within Kirkwood-Cohansey Project study areas. The same ponds chosen for the vegetation studies will be used for the anuran surveys and larval studies.

2. Use at least four transects and 1-m^2 quadrats to measure early-summer and late-summer vegetation cover. The actual number of quadrats and transects will depend on the types of vegetation zones encountered.
3. Conduct floristic surveys throughout the growing season.
4. Enter data in the Kirkwood-Cohansey Project database.

Environmental Measurements

1. Sample pH, specific conductance, dissolved oxygen, NOx, dissolved organic carbon, and water color each month during the growing season (March-October).
2. Sample substrate at one-meter intervals along transects. Measure peat thickness and quality and subjectively describe the mineral-soil texture. Complete laboratory analysis of texture, bulk density, and percentage organic matter for selected samples.
3. Use a GPS to delineate the shoreline of each pond during a period of high-water and measure water levels throughout each pond. Construct bathymetric maps for each pond.
4. Install continuous water-level recorders at selected reference ponds and establish partial-record stations at all other study ponds.
5. Determine the presence and depth of the first confining layer within 2 m of the pond bottom to determine if low-permeability horizons are present.
6. Described the dominant forest types within the four quarters of a 10-m buffer surrounding each pond.
7. Complete environmental measurements over a period of at least two years.
8. Enter data in the Kirkwood-Cohansey Project database.

Models

1. Develop and validate ordination and regression models relating intermittent-pond plant-species gradients to natural and induced changes in the depth, duration, and frequency of saturation and flooding.
2. Coordinate model development with other cooperators.

Products

A report describing study methods, results, and interpretations, ordination and regression models, and supporting data entered in the Kirkwood-Cohansey Project database.

ANURAN-LARVAL DEVELOPMENT AND RECRUITMENT SUCCESS (PC)

Central Question

How is anuran-larval development and recruitment success related to intermittent-pond hydrology?

Tasks

Task 1. Conduct field studies of anuran-larval development and recruitment success in relation to intermittent-pond hydrology.

Task 2. Develop models relating anuran-larval development and recruitment success to natural and induced changes in the depth and duration of flooding.

Study Details

Vocalization Surveys

1. Conduct vocalization surveys at the Commission's existing 20 annual-survey ponds as part of on-going long-term monitoring program.
2. Conduct vocalization surveys at selected hydrologic-study area ponds during the year prior to the anuran field studies to determine if the species pool is comparable to those at existing survey ponds and to aid in future tadpole identification.
3. Use the same ponds chosen for the vegetation studies for the anuran surveys and larval studies.

Larval-period Surveys

1. Use repeated dipnet surveys to sample several existing ponds or study-area ponds to document timing of egg laying, tadpole hatching, and metamorphic transformation for species of interest.
2. Use the results of the dipnet surveys to provide a general timeline of the natural developmental process for all anurans breeding at the ponds. Compare these results to the manipulative field experiment.

Field Experiments

1. Acquire eggs from females as they are laid (best scenario) or collect cohort tadpoles with a dipnet.
2. Target at least two species. Use either one early breeding species (e.g., spring peeper) and one late-breeding species (e.g., Pine Barrens treefrog) or two late breeders (e.g., Pine Barrens Tree Frog, Fowler's toad, or late-breeding southern leopard frog). Late breeders may be more vulnerable to pond drying than early breeders. Hatch eggs and raise tadpoles in aerated habitat in lab. Mix hatchlings from different parents before addition to enclosures to homogenize genetic differences.
3. Establish enclosures throughout a range of depths along three or four transects from the pond shoreline to the deepest portion of the pond. This hydrologic gradient can be designed to be as continuous as desired. This experiment will be replicated in three ponds.
4. Include in each area a platform for metamorphs to emerge. Enclosure mesh size will exclude insect and interspecific predators and competitors.
5. Stock enclosures with single individuals and at a natural density for each species.
6. Compare measures, such as the percentage of successful metamorphs, snout-vent length, wet mass, etc., along the hydrologic gradient. As the pond dries, tadpoles will either die or respond by initiating morphogenesis.

7. Monitor metamorphs emerging naturally from the remainder of the pond and compare them to those from the control enclosures to evaluate the effect of the enclosure.

Models

1. Develop regression models relating anuran-larval development and recruitment success to natural and induced changes in the depth and duration of flooding.
2. Coordinate model development with other cooperators.

Products

A report describing study methods, results, and interpretations, regression models, and supporting data entered in the Kirkwood-Cohansey Project database.

STREAM FISH AND MACROINVERTEBRATES (USGS WITH PC)

Central Questions

1. **How do stream fish and macroinvertebrate assemblages respond to changes in streamflow regimes?**

2. **How do site-specific habitat variables, such as temperature, dissolved oxygen, bank cover, stream vegetation, sediments, and channel morphology, interact with stream-discharge to effect fish and macroinvertebrate composition?**

Tasks

Tasks 1. Select study sites with variable discharge regimes.

Task 2. Conduct field characterization of stream-fish assemblage and macroinvertebrate-community gradients, focusing on headwaters.

Task 3. Monitor relevant site-specific environmental factors, including pH, specific conductance, dissolved oxygen, temperature, stream discharge, stage, channel dimensions, substrate type, bank vegetation, and site history and characterize regional factors, including basin area and land use/land cover. Coordinate activities with the USGS hydrologic monitoring efforts.

Task 4. Develop appropriate ordination and regression models relating community gradients to natural and induced changes in the streamflow regimes.

Study Details

Selection of Study Sites

1. Use available data to establish a relationship between discharge and basin area and use this relationship to select eight discharge-type stream reaches in the Batsto River basin, focusing on basin areas that are less than 50 km^2.
2. Within each Batsto River discharge-type stream reach, select four separate 100-m sampling sections that represent different habitats characterized by forest versus non-forest banks and variable velocity due to variations in stream-channel width. Together, these two factors influence sediments, temperature, dissolved oxygen, and aquatic-vegetation abundance.
3. Select a total of twelve 100-m sampling sections in the Morses Mill Stream and Pump Branch/Alberston Brook basins to validate the relationships developed in the Batsto River basin.

Fish Surveys

1. Conduct fish surveys under high-flow (May-June) and low-flow (September-October) periods. Sample all stream reaches within a short time period to minimize seasonal variations in flow between sites.
2. During each sampling event, use block nets, nylon seines, and electrofishing to survey fish in all habitats within each sampling reach for a period of 1 hr. Use dip nets if necessary.
3. Identify, count, and measure all fish collected.

Aquatic Invertebrate Assessment

1. Following procedures similar to those outlined by the Mid-Atlantic Coastal Stream Workgroup (USEPA 1997), collect multi-habitat aquatic invertebrate samples within the same 100-m fish-sampling reaches. Invertebrate sampling will be conducted before fish inventories.
   a. Collect approximately 20 D-net jab samples distributed proportionally throughout targeted habitats, including banks, woody snags, submerged macrophytes, and muck.
   b. Composite and process the 20 discrete D-net samples to provide an integrated and representative aquatic-invertebrate sample for each 100-m reach.

Habitat Measurements

1. Except for water quality and stream discharge, each measurement should be made at transects established every 25 m within each 100-m reach.
2. Complete monthly pH, specific conductance, dissolved oxygen, and temperature measurements at a single point within each discharge-type stream reach (PC).
3. Complete all measurements under baseflow conditions throughout the growing season.
4. As part of the hydrologic investigation, measure discharge and stage at a single point within each discharge-type stream reach under a range of flow conditions and measure stage monthly at each point during the growing season
5. Measure channel cross-sections (width of flow and flow depth, bankfull width and depth).
6. Collect substrate sample at left and right side of channel and in thalweg for subsequent textural analysis by feel or comparison to reference samples.
7. Complete plant-species list and estimate floating-leaved, free-floating, submerged, and emergent plant cover at left and right side of channel and in thalweg using a 0.5 x 0.5 m quadrat (PC).
8. Describe adjacent-forest type and measure bank cover (as surrogate for shading) using a spherical densiometer (PC).

Models

1. Develop appropriate ordination and regression models relating Batsto River community gradients to natural and induced changes in the streamflow regimes.
2. Validate Batsto River community-gradient models using Morses Mill Stream and Pump Branch/Albertson Brook data.

Products

A report describing study methods, results, and interpretations, ordination and regression models, and supporting data entered in the Kirkwood-Cohansey Project database.

ECOLOGICAL PROCESSES: NITROGEN (RUTGERS)

Central Question

Will unsaturated conditions associated with lowered water-table levels promote increased nitrogen mineralization and nitrification, resulting in pulses of mineral nitrogen to wetland and aquatic systems?

Tasks

Task 1. Conduct a laboratory study of the effect of variable moisture regimes on mineralization and nitrification.

Task 2. Conduct a simultaneous field study of the effect of variable moisture regimes on mineralization and nitrification and evaluate the potential for the release of nitrogen to wetlands.

Study Details

Laboratory Study

1. Collect representative organic-soil materials from two palustrine-wetland study plots with peat soils within the McDonalds Branch study area.
2. Use a standard Stanford-Smith 30 week incubation method to determine mineralization rates and potentially mineralizable nitrogen for samples incubated at five moisture levels (continuously saturated, continuously maintained at 80%, 60%, and 40% water-holding capacity, and alternating saturated/unsaturated in two-week periods). This method provides information on the rate of mineral nitrogen (nitrate and ammonium) production, the relative amounts of the two forms produced, and the long-term potential for soils to continue to produce mineral N.
3. Relate the results of the laboratory study to the following field study.

Field Study

1. Conduct a field study at the same two wetland-forest study plots to determine whether increased production of mineral nitrogen under variable moisture regimes results in excess nitrogen within the wetlands.
2. Use a modified buried-core method[5] to measure in-situ rates of nitrogen mineralization in sequential samples throughout a one-year period. Cores will be retrieved and replaced on a three-week interval during the growing season, and monthly to bimonthly during the winter.
   a. Take one sample to the laboratory for extraction of mineral-nitrogen fractions.
   b. Place a second adjacent sample in a PVC tube and incubate it in the field for 2-3 weeks, retrieve it, and determine the mineral-nitrogen content.
   c. Measure water-table level, soil moisture, and temperature at the time of sample collection and retrieval using same methods employed in the wetland-forest gradient study.
3. Within each plot, install two porous-cup lysimeters at a depth of 50 cm and sample interstitial water at the time that the cores are retrieved and replaced. Soil water samples will be analyzed for inorganic N (NH_4 and NO_3) and DON (dissolved organic nitrogen) to determine leaching.
4. Relate the results of the field study to the laboratory study.

Products

A report evaluating the potential for the release of nitrogen to wetlands due to variable hydrology.

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[5] The specific buried-core method for use in saturated-organic soils must still be determined.

ECOLOGICAL PROCESSES: INDICATORS OF PHYSIOLOGICAL STRESS (RUTGERS)

Central Question

How do variations in hydrologic regime affect the water relations and photosynthetic rates of wetland plants?

Tasks

Task 1. Compare the water stress displayed by selected indicator-plant species in relation to seasonal and annual variations in hydrologic regime along upland to wetland gradients.

Task 2. Compare the photosynthetic capacity of selected indicator-plant species in relation to seasonal and annual variations in hydrologic regime along upland to wetland gradients.

Study Details

Field Study

1. Use three dry lowland, three wet lowland, and three swamp sites studied as part of the wetland-forest gradient study. Sites will be selected so that each of four indicator species (highbush blueberry, fetterbush, sweet pepperbush, and dangleberry) is found under conditions representing its hydrologic range.
2. Relevant environmental and vegetation (structure and composition) data will be collected through the wetland-forest gradient study.
3. Randomly select four "individuals" of each indicator species and measure pressure potentials, A/Ci curves, and stomatal conductance over a two year period.
4. Measure pre-dawn and mid-day pressure potentials (ψ) on selected individuals twice monthly during the growing season (leaf emergence to leaf fall).
5. Measure stomatal conductance to water vapor (g_s) and instantaneous net photosynthetic assimilation rates (A_{net}) on the selected individuals 3-4 times per growing season (i.e., May, early July, August, late September) under ambient light, temperature, and humidity conditions using the Licor 6400 system.
6. Use the LiCOR 6400 portable photosynthesis unit to generate A/Ci (a measure of photosynthetic demand capacity relative to stomatal supply) derived parameters of maximum electron transport capacity (J_{max}) and maximum carboxylation velocity (V_{cmax}). These parameters provide mechanistic data on the regulatory responses of photosynthesis to changes in resource availability.
7. Microclimate, including air temperature, windspeed and wind direction, relative humidity, and photosynthetically active radiation (PAR), will be measured during the evapotranspiration-monitoring study.
8. Weather station data will be collected as part of coordinated basin-wide monitoring efforts.

Products

A report evaluating the effect of varying hydrologic regimes on the water relations and photosynthetic capacity of indicator species as physiological indicators of stresses that could eventually lead to changes in community composition.

LANDSCAPE MODELS (RUTGERS WITH COOPERATORS)

Central Questions

1. **How does the landscape-scale distribution of wetland-forest community types and indicator species respond to changes in water-table regime?**

2. **How does the distribution of individual species and vegetation zones in intermittent-ponds respond to changes in water-level regime?**

3. **How does the landscape-scale distribution of stream fish and macroinvertebrate assemblages respond to changes in stream flow?**

Tasks

Task 1. Develop spatially distributed models at a landscape scale relating the distribution of transitional-upland (e.g., mesic pine-scrub oak) and wetland-forest community types (e.g., dry pitch pine lowland forest, hardwood swamp) and indicator species to environmental gradients (**Rutgers and PC).**

1. Translate the results of the empirically determined wetland-forest community-gradient models to develop spatially distributed models using a GIS database of mapped environmental characteristics.
2. Analyze the effect of various scenarios of natural and induced changes in the duration and frequency of saturation and flooding on the spatial distribution of wetland-forest community types and indicator species (i.e., shifts in community types associated with changes in water-table patterns).

Task 2. Develop spatially distributed models at a landscape scale relating the distribution of stream fish and macroinvertebrate communities to environmental gradients. **(USGS and Rutgers)**

1. Translate the results of the empirically determined stream-community gradient models to develop spatially distributed models using a GIS database of mapped environmental characteristics.
2. Analyze the effect of various scenarios of natural and induced changes in stream flow or depth on the distribution of stream communities.

Task 3. Develop spatially distributed model relating intermittent-pond-vegetation gradients to environmental gradients. **(PC and Rutgers)**

1. Translate the results of the empirically determined pond-vegetation gradient models to develop a spatially distributed model using a GIS database of mapped environmental characteristics.
2. Analyze the effect of various scenarios of natural and induced changes in the duration and frequency of saturation and flooding on pond vegetation.

Task 4. Develop spatially distributed models at a landscape scale to estimate the ecosystem-level processes of evapotranspiration and photosynthesis. (**Rutgers and USGS**)

1. Modify existing spatially distributed models (e.g., BiomeBGC or PnET) to model wetland-ecosystem processes at the landscape scale.
2. Analyze the effect of various scenarios of natural and induced changes in the duration and frequency of saturation and flooding on the ecosystem-level processes of evapotranspiration and photosynthesis.

Products

Linked GIS/simulation models with supporting documentation and report.

Study Details

Wetland-forest Community-gradient Models

1. For each study basin, compile a GIS database that includes as attributes the physical/environmental parameters used in developing the empirically determined wetland-forest-community gradient models. The GIS database will be in a grid-cell-based format at a spatial resolution yet to be determined. Possible GIS-based factors include:
   a. Slope and aspect estimated from 10-m NJDEP digital-elevation models or 30-m seamless USGS digital-elevation models.
   b. Hydrological parameters, such as depth to the water table, estimated based on the output from the hydrological-modeling efforts.
   c. Soil characteristics estimated using soil types (e.g., factors such as depth of the O horizon, percentage organic matter, and soil moisture change along the Lakewood–Lakehurst–Atsion–Berryland gradient). Additional spatial modeling and interpolation may be incorporated to improve the spatial estimation of the soil characteristics.
2. In each study basin, characterize the spatial correspondence of the wetland-community types, represented by the NJDEP freshwater-wetlands coverage, and modeled water tables.
   a. Evaluate the level of correspondence between modeled water-tables and those determined through field studies to be associated with wetland-vegetation types represented by NJDEP freshwater wetland coverage (e.g., PFO4). Consider the effect of other GIS-based factors such as soil texture.
   b. Use the modeled water-table data to further differentiate individual wetland-community types into appropriate relative-wetness classes. For example, mapped pitch pine lowlands (PFO4) could be further delineated and mapped into "wetness types" such as wet PFO4 and dry PFO4.
   c. Undertake spatial analysis of the effect of various scenarios of natural and induced changes in the duration and frequency of saturation and flooding on the spatial distribution and pattern of the mapped wetland-community types across the landscape.
3. Translate the results of the empirically determined wetland-community-gradient models into GIS-based community-gradient models.
   a. Use the GIS-based models to estimate the locations (or range of locations) of individual wetland-community types under natural and various scenarios of induced hydrologic regimes, documenting the changes in the spatial distribution and pattern of the wetland communities across the landscape.
   b. Evaluate the level of correspondence between estimated wetland-community types and those represented by NJDEP freshwater wetland coverage.
4. Translate the results of the empirically determined indicator-species models into GIS-based models. One advantage of indicator species models is that the individual species may behave differently under the hydrologic-change scenarios.
   a. Use the GIS-based model to estimate the locations (or range of locations) of individual species under natural and various scenarios of induced hydrologic regimes.
   b. Assemble indicator species to create wetland communities under natural and various scenarios of induced hydrologic regimes, documenting the changes in the spatial distribution and pattern of the constructed vegetation communities across the landscape.
   c. Evaluate the level of correspondence between estimated wetland-community types constructed using indicator species and those determined through the GIS-based community-gradient model and represented by the NJDEP freshwater-wetland coverage.

Stream Models

1. Compile a GIS database that includes as attributes the physical/environmental parameters used in the developing the empirically determined stream-community gradient models. This GIS database will be in a vector based format with each stream reach stored as a segment within a larger stream network.
    a. Estimate hydrological parameters (e.g., start of flow and flow amount) based on the output from the hydrological-modeling effort.
    b. Use the USEPA/USGS 1:100,000 National Hydrography database (part of the USEPA's Watershed Assessment Tracking and Environmental Results system (http://www.epa.gov/waters) as the stream-network data source. Use 1:24,000 hydrography data to supplement or replace the 1:100,000 data as needed.
2. Translate the results of the empirically determined stream-community gradient models into a GIS-based community-gradient model. The models may incorporate various environmental parameters such as stream flow, stream order, vegetation cover, and substrate.
3. Use the GIS-based models to estimate the locations (or range of locations) of stream fish and macroinvertebrate community types.
4. Develop and implement methods to validate the models.

Intermittent-pond Models

1. Compile GIS database for individual ponds that include as attributes the physical/environmental parameters used in the developing the pond-vegetation gradient models.
2. Translate the results of the empirically determined pond-vegetation gradient models into individual GIS-based models used to estimate the spatial distribution of individual plant species and vegetation zones and the overall pond composition.
3. Evaluate various change scenarios by altering water levels and mapping the resulting changes in the vegetation of individual ponds.
4. Generalize the results of the pond models to other similar ponds to examine shifts in pond characteristics at the landscape scale.
5. Develop and implement methods to validate the models.

Physiological-Stress Models

1. Translate the results of the physiological-stress study into GIS-based models used to estimate changes in water stress and photosynthesis associated with various water-level change scenarios.
2. Develop and implement methods to validate the models.

Products

GIS models relating landscape-scale changes in species, biological communities, and ecosystem processes to changes in hydrologic regimes and a report describing the study methods, results, and interpretations.

BUILD-OUT AND WATER-DEMAND SCENARIOS (PC)

Central Questions

1. **At what rate will population and dwelling units be expected to grow within the Pinelands area and what pattern of dispersion may occur at build-out?**

2. **What demand is placed on water supplies by residential, commercial, and agricultural land use, how will these patterns be expected to change in the future, and what is the implication for total future water demand within the Pinelands area?**

Tasks

Task 1. Collect geographic data necessary for build-out analysis.

Task 2. Collect data on current water consumption, ensuring consistency with the State Water Supply Master Plan update.

Task 3. Collect data to estimate pace and amount of future land-use changes and their impact on water-consumption patterns.

Task 4. Prepare the data for use in a build-out analysis.

Task 5. Conduct a build-out analysis for all Pinelands municipalities.

Task 6. Estimate current total-water usage/consumption by combining residential, commercial, and agricultural components.

Task 7. Estimate future total-water usage/consumption using a range of possible scenarios based on researched trends in water usage/consumption.

Study Details

Geographic Data for Build-out Analysis

1. Utilize existing parcel data for all 53 Pinelands municipalities.
2. Use NJDEP 1995 land-cover data to assess fresh water wetlands, water bodies, developed land, and extractive mining, dredge spoil, or disturbed wetlands sites.
3. Use existing Pinelands Commission geographic data to determine municipal and Pinelands zoning.
4. Obtain data on public lands, hydric soils, and watershed boundaries from existing NJDEP coverages.

Current Water-consumption Data

1. Use 2000 census data to determine current population and number of households.
2. Obtain the best available data on septic vs. sewer use for households and businesses.
3. Estimate residential water-use factors (gal/person/day, gal/household/day, gal/acre/day) using data from USGS, NJDEP, MUAs.
4. Calculate water-loss factors, i.e., the percentage of water use that is consumptive prior to wastewater treatment.
5. Determine the amount of water recharge from sewage-treatment plants, based on data from MUAs, NJDEP, and the municipalities.

6. Estimate the extent of commercial development by type of user, square footage, and number of employees.
7. Estimate commercial water-use factors (gal/ft^2/day, gal/employee/day) using data from USGS, NJDEP, and national-interest groups.
8. Calculate crop acreages using data from USDA and NJDOA as well as the NJDEP land-cover data.
9. Estimate "by crop" water-use factors (gal/acre/day) and water-loss factors using data from USGS, USDA, NJDOA, and NJDEP.
10. Study the water use/loss attributes of various irrigation techniques (USGS, USDA/NRCS are possible sources of information).

Land-use Change Projections

1. Obtain future population projections from OSP, DOL, Pinelands analyses, and other sources.
2. Make economic projections based on Commission data and information from US OECD, NJ EDA, and Rutgers.
3. Project future crop acreages and agricultural trends based on information from USDA, the Farm Bureau, and Rutgers.

Preparation of Build-out Analysis Database

1. Update all Pinelands zoning coverages with per-unit densities to include minimum-lot sizes and commercial intensity.
2. Create a comprehensive coverage of public land.
3. Create databases in preparation for build-out and water-usage calculations.

Build-out Analysis for Pinelands Municipalities.

1. Calculate vacant, developable land on a by-parcel basis for each municipality after making necessary adjustments for public land, water bodies, wetlands, and existing development.
2. As a check, conduct a parallel analysis using municipal zones, rather than parcels, as the underlying geographic unit.
3. Determine potential-buildable units based on the vacant, developable land and underlying zoning density/minimum lot-size factors.
4. Calculate future units based on potential-buildable units and existing units as determined using 2000 census-block data and the 1995 NJDEP land-cover data.
5. After determining zone capacity, use development-efficiency factors, building trends, and other data sources to reduce the estimates to build-out for a number of future scenarios.
6. If feasible, use available projections to estimate the pace of development to the year 2025.
7. Project commercial "build-out" using the same methodology as for the residential projections.
8. Project agricultural "build-out" in agricultural zones and elsewhere based on trends, soils, and other available information.

Current Water Usage/Consumption

1. Calculate the residential component based on population, number of households, residential acreage, and residential water use/loss factors. Estimates will be compared to wastewater-exportation figures.
2. Calculate the commercial component based on retail, office, warehouse, and industrial square footage/acreage, number of employees, and commercial water use/loss factors. Estimates will be compared to wastewater-exportation figures.
3. Calculate the agricultural component based on crop acreages by type, irrigation techniques, and agricultural water use/loss factors. Estimates will be compared to existing well data.

Future Water Usage/Consumption Estimates

1. Create a range of scenarios projecting future residential-water demand by multiplying housing units by water usage/consumption factors on a subwatershed basis.
2. Create a range of scenarios projecting future commercial-water demand by multiplying commercial square footage by water usage/consumption factors on a subwatershed basis.
3. Create a range of scenarios projecting future agricultural-water demand by multiplying estimated future by-crop acreages by water usage/consumption factors on a subwatershed basis.

Products

A report that includes the detailed results of the build-out and water-demand analyses, including information on derivation and sources of factors, documentation of calculations, and data limitations. The report will also include maps, graphs, and charts needed to support the build-out and water-demand estimates. Findings will be presented on a subwatershed basis and may also be broken down by municipality.

DATA MANAGEMENT AND DATA-ANALYSIS COORDINATION (USGS)

Task 1. Design and Implement a Kirkwood-Cohansey Project Database

1. Identify data-sharing needs and data-management objectives.
2. Identify data types to be handled in the data-management system. Some data are point specific, some are area specific, and any of these types can have multiple data values through time. The database system will need to account for these variants.
3. Identifying linkages between data types (e.g., water levels connected in support of ecological transect studies may be stored in common with water levels collected in support of a hydrologic study, however linkages will need to be fashioned to relate to originating source).
4. Design an appropriate data model that will incorporate all of the different types of data and linkage needs.
5. Specify the data formats, transfer protocols, quality assurance and update procedures, and version control needed to ease transfer and quality assurance needs.
6. Construct the data management system to run on a PC based system relying on Microsoft Access database software and ArcMap GIS software. This system will be compatible with that used for the landscape modeling components of this project.
7. Administer the data-management system. Each project group of the overall effort will be required to transmit or enter computerized data to the data management system. The data management system will provide the avenue for sharing, quality control and other applications.

Task 2. Coordinate Data Analysis

1. Coordinate data-analysis methods used to develop ordination and regression models resulting from the different ecological studies.
2. Review data analysis results.

OTHER WORK PLAN TASKS

Public Information (PC)

Task. Develop a program to inform cooperators and the public about the purpose, approach, and progress of the Kirkwood-Cohansey Project.

1. Establish and maintain a web page.
2. Prepare annual press releases.
3. Convene annual meeting among representatives of cooperating agencies and institutions.
4. Organize initial public meeting and two subsequent public meetings (every two years).

Products

Web page and press releases.

Final Kirkwood-Cohansey Assessment (PC with Cooperators)

Task. Compile individual study results as separate chapters and produce a comprehensive report.

Product

Final comprehensive report.

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