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June 15, 2012

Final Report: Pinelands Science-Policy Forum on the Kirkwood Cohansey Aquifer

Pinelands Preservation Alliance (PPA) is pleased to provide the final report for the Pinelands Science-Policy Forum held on March 13 and 20, 2012. This forum focused on water supply planning for the Kirkwood Cohansey Aquifer.

The two-day forum provided an overview of the current scientific research on the Kirkwood Cohansey (KC) Aquifer and its land use implications, and developed consensus policy measures on planning for the sustainable use of the aquifer. This report provides all the information presented to the participants on the day of the forum and details those policy measures identified as relevant for water supply planning in the Pinelands.

This document can be distributed widely, so please feel free to share with other colleagues and the general public. PPA also welcomes comments, questions, and opportunities for presentations. You can contact Jaclyn@pinelandsalliance.org to share this information or call PPA's office at 609-859-8860 ext. 18.

Sincerely,

Jaclyn Rhoads

Jaclyn Rhoads, Ph.D.
Director for Conservation Policy

Report and Summary

Pinelands Science-Policy Forum on

The Kirkwood Cohansey Aquifer System

June 14, 2012

Purpose: This Science-Policy Forum aimed to foster a well-informed, science-based discussion of the stewardship and sustainable use of the Kirkwood-Cohansey aquifer, ultimately leading to a measure of consensus around key policy choices which face the two state agencies with direct regulatory authority over the aquifer: the Department of Environmental Protection ("DEP") and the Pinelands Commission.

This discussion was sparked by a wide recognition that human uses of the aquifer can, and at least in some cases already do, have negative effects on the ecology of the Pine Barrens and coastal estuaries which rely in a variety of ways on the aquifer.

The completion and imminent publication of the Kirkwood-Cohansey Aquifer Study ("K-C Study") carried out by the US Geological Survey, the Pinelands Commission, DEP, Rutgers University researchers and the U.S. Fish and Wildlife Service, provided a rigorous scientific basis for the forum discussion.

> *The results summarized here reflect the group's overall direction of the discussion that took place, but do not show that any given participant agrees with or has committed to the policy and implementation options we discussed. Once a policy agenda has been refined and completed, participants and others will have the opportunity to sign on to the agenda if they choose, but that step lies ahead of us.*

Organizers: The Forum was organized by a steering committee consisting of Pinelands Preservation Alliance, the Great Egg Harbor Watershed Association, American Littoral Society, Dr. Claude Epstein, Professor Emeritus of Environmental Science at Richard Stockton College, and Robert Kecskes – retired from NJDEP. Staff of the Pinelands Commission, New Jersey American Water, and the US Geological Survey provided technical information on the scientific studies, input on the forum briefing materials, and presentations on the results of the K-C Study.

Attendees: The Forum attendees were individuals whose professional or volunteer activities give them relevant experience and expertise on the Kirkwood-Cohansey aquifer and its uses. A list of attendees, and others who were invited but could not attend, is attached as Appendix A. We noted at the start of the Forum that participants had a variety of jobs and affiliations, and specifically that some were employees of government agencies which have not taken formal positions on the policies we were discussing. We therefore recognized that a person's question and statement did not necessarily reflect the position of his or her employer.

Structure: The Forum was structured to maximize discussion and measure responses to policy options over two days. The organizers provided an extensive briefing paper to all

attendees in advance of the Forum in order to foster a common base of information given the complex nature of the K-C Study and the scientific and policy matters under discussion. A copy of the briefing materials is attached as Appendix B.

The first part of the forum was held on March 13th to review and better understand the aquifer studies conducted by the US Geological Survey on detailed modeling of the aquifer, and the Pinelands Commission science program and Rutgers University Geospatial Center on the ecological impacts of water withdrawals from the Kirkwood-Cohansey aquifer. Pinelands Commission staff presented on the build-out analysis to be completed by the planning staff as part of the K-C Study, and Robert Kecskes (NJDEP retired) provided an overview of water supply alternatives.

The second part of the forum was held on March 20th to discuss the range of policy options for controlling impacts of new or increased allocations and water supply planning (see Appendix C for powerpoint on policy options). We used anonymous key-pad polling to measure and display the group's views of specific policy and planning options. Facilitators summarized a range of policy options; we then broke into smaller groups for further discussion and brainstorming; and finally reconvened for facilitated plenary discussions and polling of the group's views of policy and planning options.

It is important to note that a number of participants chose not to do the keypad polling. In most or all cases, those who did not use the keypad polling did so because they felt it might be inappropriate due to their employment or association with state government agencies.

Polling Methodology: The key pad polling was anonymous, and a few participants did not participate in the polling by their own choice. The possible responses for all polling questions were:

1 – Agree and High Priority

2 – Agree and Low Priority

3 – Agree but not possible/practical

4 – Disagree – not effective and/or not worth pursuing

Polling results were immediately displayed for the group as the percentages choosing each answer. The full text of the polling options can be found in Appendix B and D, and the polling results are attached as Appendix D.

Results: The Forum discussions and polling resulted in a strong consensus on many key points and set clear direction for further work to flesh out details and resolve remaining areas of uncertainty. The points of consensus and uncertainty are summarized below.

For purposes of measuring consensus, we are treating as a point of consensus those options for which 85% or more of participants selected responses of 1, 2 or 3 – meaning they thought it was a good idea. In some cases, however, a large percentage of participants felt the option was not possible or practical (response 3), and those cases are noted in this summary. The points of consensus and uncertainty are summarized below.

A. *Rules for Controlling Impacts of New or Increased Allocations*:

There was strong support for a number of policy options, including most prominently to:

- ✓ For impacts on streams and rivers: Institute ecologically-based thresholds for new or increased allocations from the Kirkwood-Cohansey by using low flow margin, percent of 7Q10, or percent of drought of record, but with the ecological passing flow as a floor or limit in all cases.
- ✓ For impacts on wetlands: Require species-specific and Pinelands pond-specific criteria for judging acceptable versus unacceptable impacts of withdrawals on wetlands.
- ✓ Require quantifiable water conservation measures in the same sub-watershed to offset expected impacts of new and increased withdrawals.
- ✓ Incentivize all water conservation measures as part of permitting for new or increased allocations.
- ✓ Set a regulatory trigger that suspends new or increased allocations, or reduces existing allocation limits, in a watershed when a trend of increasingly severe impacts of current withdrawals shows the modeling on which permits are based is inaccurate.
- ✓ Require recipients of allocations to monitor and report streamflow and water table changes in the future.

There was support for, but also greater concern with practicality and some opposition regarding two additional policy options:

- ✓ Permit no wetland reduction at all for applications for a new or increased allocation from the KC aquifer.
- ✓ Require all applicants to show other sources are not available before using the KC aquifer or in cases of a disfavored or optional use.

B. *Water Supply Planning*:

Through the course of the discussion, it became clear that the scientific community and government agencies do not have a description or quantification of the impacts existing Kirkwood-Cohansey withdrawals have already on streams, wetlands and estuaries that rely on the aquifer. While not voted on as a specific policy option, there was widespread agreement that an understanding of current, cumulative impacts of withdrawals is important to managing future withdrawals and conservation measures.

There was strong agreement that water allocation planning for the Kirkwood-Cohansey aquifer be instituted and structured to:

- ✓ Set targets for total withdrawals from the aquifer in each basin/sub-basin and provide suggested water supply alternatives.

- ✓ Set limits on total withdrawals from the aquifer in each basin and identify required water supply alternatives.
- ✓ Design plans to maintain current ecological functions and restore natural flow and water levels where existing withdrawals have already reduced flows or water levels.

There was nearly universal agreement that DEP and the Pinelands Commission should incorporate water supply alternatives into water supply planning to:

- ✓ Set explicit criteria for determining when each potential alternative source will be considered available, desirable and required for consideration by purveyors.
- ✓ Incorporate water supply alternatives into targets, limits and options for those basins where the aquifer is already stressed.
- ✓ Incorporate impacts to and withdrawals from connected aquifers, such as the Atlantic City 800-foot Sands.

Next Steps: The organizing committee has agreed to facilitate next steps towards advancing this consensus-building process and bringing more people and organizations into the discussion:

1. The organizing committee will distribute this report of the Forum to participants for their review and comments, which the committee will use to finalize the report.
2. The full Kirkwood-Cohansey Aquifer Study is not yet published, so the organizing committee will help publicize the study reports when they are all published in order to permit further analysis and discussion of the full study results.
3. The organizing committee will seek to brief the Commissioner of DEP, water supply purveyors, state legislative leaders, and other interested government leaders on the progress of our discussions. The committee will invite other Forum participants to join in these briefings if they wish.
4. The organizing committee will seek to present the Forum discussion to environmental commissions, NGO's, planning boards and town councils. Again, the committee will invite other Forum participants to join these briefings.
5. The organizing committee will schedule another, larger gathering to review what progress DEP and the Pinelands Commission have made in managing and planning use of the Kirkwood-Cohansey aquifer, probably at the beginning of 2013.

Appendix A
Invites to Pinelands Science-Policy Forum on Kirkwood Cohansey Aquifer System
March 13 and 20, 2012

Affiliation	FirstName	LastName
Great Egg Harbor Watershed Association	Frederick B.	Akers
Pinelands Commission	Candace	Ashmun
Jacques Cousteau National Estuarine Research Reserve	Lisa	Auermuller
Drexel University	Harold	Avery
ACUA	Nicole	Bacher
Stockton College	Tracy	Baker
PPA Trustee	James	Barnshaw
NJ Dept. of Environmental Protection	Thomas	Belton
Burlington County Department of Resource Conservation	Gina	Berg
Drexel University	Walt	Bien, Ph.D.
Pinelandsa Preservation Alliance	Richard	Bizub
Hamilton Twp. MUA	Steve	Blankenship
Montclair State University	Paul	Bologna
N.J. Geological and WaterSurvey	Jim	Boyle
Brinkerhoff Environmental Consulting	Laura	Brinkerhoff
The Nature Conservancy	Barbara	Brummer
Pinelands Commission Science Office	John	Bunnell
The Bloustein School	Robert	Burchell
Rutgers University	Joanna	Burger
Pinelands Commission	Patrick	Burritt
William Patterson Univeristy	Jennifer	Callanan, Ph.D.
Association of NJ Enviornmental Commissions	Johanna C.	Carrara
Central Pine Barrens Commission	Anne	Carter
DEP Natural Areas and Heritage Programs	Bob	Cartica
USGS	Stephen	Cauller
USGS	Emmanuel	Charles
US Forest Service	Ken	Clark
Stockton College	Richard H.	Colby
Central Pine Barrens Commission	Ray	Corwin
Department of Environmental Protection	Amy	Cradic
The Nature Conservancy	Ellen	Creveling
Richard Stockton College	Jamie	Cromartie
Save Barnegat Bay	Willie	deCamp Jr
Rutgers University IMCS JCNERR	Michael	DeLuca
University of Delaware	Mark	Demitroff
ACUA	Matthew	DeNafo
Egg Harbor City	Edward	Dennis, jr.
New Jersey Conservation Foundation	Emile	DeVito
Pinelands Field Station	John	Dighton, Ph.D.
American Littoral Society	Tim	Dillingham
Doran Engineering	Matt	Doran
Atlantic County Utilites Authority	Richard	Dovey
Victoria Foundation	Craig	Drinkard
DVRPC	Patty	Elkis
Richard Stockton College	Claude	Epstein, Ph.D.
Maser Consulting	Wayne	Ferren
Pinelands Commission	Leslie	Ficcaglia
Waterwatch International	Joel	Fogel
PPA	Rebecca	Free
Ocean County Soil Conservation District	David B	Friedman
Richard Stockton College	Michael	Geller, Ph.D.
NJ Institute of Technology	Eugene	Golub,Ph.D.
Pinelands Commission	Susan	Grogan

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March 13 and 20, 2012

CRSSA JCNERR	Scott	Haag
Pinelands Commission	John	Haas
Barnegat Bay Natl Estuary Program	Stan	Hales
	Susan D	Halsey PhD
Jackson MUA	David	Harpell
National Park Service	Rick	Harris
Rowan University	John	Hasse
DVRPC	Alison	Hastings
	Anne	Heasly
American Littoral Society	Helen	Henderson
N.J. Geological & Water Survey	Jeffrey	Hoffman
	Robert	Hordon, Ph.D.,P.H.
Pinelands Commission	Chuck	Horner
Pinelands Commission	Robert	Jackson
NJ Division of Fish and Wildlife	David	Jenkins
Rider University	Dr Paul A	Jivoff
New Jersey Geological & Survey	Steve	Johnson
University of Pennsylvania	Dr. Arthur	Johnson
William Penn Foundation	Andrew	Johnson
New Jersey Conservation Foundation	Glenn R.	Juelg
Department of Environmental Protection	Marjorie	Kaplan
Brick MUA	Rob	Karl
Ramapo College of New Jersey	Eric	Karlin
PPA	Amy	Karpati, Ph.D.
	Robert A.	Kecskes
Raritan Valley Community College	Jay	Kelly
Rutgers University IMCS	Dr Mike	Kennish
The Fund for New Jersey	Jenny-Ann	Kershner
University of Delaware	Andrea	Kornbluh
PPA	Blanche	Krubner
Pinelands Commission Science Office	Kim	Laidig
Rutgers University	Dr Richard	Lathrop
DVRPC	Shawn	Legendre
PPA	Theresa	Lettman
Pinelands Commission	Larry	Liggett
DVRPC	Chris	Linn
Columbia Law School Environmental Law Clinic	Ed	Lloyd
Pinelands Commissioner	Mark	Lohbauer
CH2M Hill	Mark	Lucas
Atlantic County Planning	Joseph	Maher
NJDEP DWM	Bob	Mancini
NJ American Water	David	Marino
US Fish and Wildlife Service	Steven	Mars
Department of Environmental Protection	Robert	Martin
Great Egg Harbor Watershed Association	Lynn	Maun
BBNEP	Martha	Maxwell-Doyle
Watershed Ambassador 19	Brittany	McGee
Pinelands Commissioner	Ed	McGlinchey
Ocean County, Planning Department	Dave	McKeon
DVRPC	Amy	Miller
New Jersey Conservation Foundation	Alison	Mitchell
Rutgers Cooperative Extension	Richard	Mohr
NJ American Water	Vincent	Monaco
PPA	Carleton	Montgomery

Appendix A
Invites to Pinelands Science-Policy Forum on Kirkwood Cohansey Aquifer System
March 13 and 20, 2012

PPA	Dave	Moore
Stockton	Daniel	Moscovici
Atlantic City MUA	Garth	Moyle
N.J. Geological & Water Survey	Dr. Karl	Muessig
TRC Solutions	Daniel	Nachman
USGS	Tony	Navoy
USGS WRD	Robert	Nicholson
The Nature Conservancy	Damon	Noe
Environment New Jersey	Doug	O'Malley
Rutgers Cranberry and Blueberry Research Station	Peter	Oudemans
	John	Peterson
NJDEP DWM	Kerry Kirk	Pflugh
Montclair State Univeristy	Greg	Pope
Pinelands Commissioner	Rick	Prickett
NJ Environmental Federation	David	Pringle
Pinelands Commission Science Office	Nick	Procopio, Ph.D.
Academy of Natural Sciences	Tracy	Quirk
	Christine	Raabe
PPA	Jaclyn	Rhoads, Ph.D.
PPA	Jessica	Rittler Sanchez
Pinelands Commissioner	D'Arcy	Rohan Green
PPA Trustee	Leon	Rosenson
Highlands Coalition	Elliott	Ruga
Clean Ocean Action	Heather	Saffert, Ph.D.
ACUA	Greg	Seher
Delaware Valley Regional Planning commission	Barry	Seymour
NJ Dept. of Environmental Protection	Fred	Sickels
Highlands Coalition	Julia	Somers
New Jersey Audubon Society	Eric	Stiles
	John	Stokes
New Jersey Future	Chris	Sturm
NJ Sierra Club	Jeff	Tittle
PPA	Robert	Tucker
Highlands Council	Daniel	Van Abs, Ph.D.
Ecological Solutions	Michael	VanClef, Ph.D.
Rutgers Ag. Experiment Station	Richard	VanVranken
ACUA	Matthew	VONDERHAYDEN
Geraldine R. Dodge Foundation	Margaret	Waldock
M&R Soil Investigations	Douglas	Walker
NJ DEP	Kathy	Walz
New Jersey Pinelands Commission	Edward	Wengrowski
Pinelands Commission	Nancy	Wittenberg
Georgian Court University	Louise	Wootton
	Robert	Zampella, Ph.D.

Appendix B: Science-Policy Forum on the Kirkwood-Cohansey Aquifer System

Forum Briefing Report

These materials are designed to provide key background information and a summary of the policy questions and options to be discussed at the Forum on March 13 and 20. Please review them before the Forum!

These materials are summary in form, but they provide references and, where available, hyperlinks to the underlying papers, reports and rules. Unless otherwise specified, these materials were prepared by the Pinelands Preservation Alliance with assistance from Fred Akers (Great Egg Harbor Watershed Association), Robert Kecskes (DEP water planner, retired), and Dr. Claude Epstein (Richard Stockton State College, retired).

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I. Introduction

This Science-Policy Forum aims to foster a well-informed discussion of the stewardship and sustainable use of the Kirkwood-Cohansey aquifer, leading to a measure of consensus around key policy choices which face the two state agencies with direct regulatory authority over the aquifer: The Department of Environmental Protection ("DEP") and the Pinelands Commission.

This discussion is sparked by a wide recognition that human uses of the aquifer can, and at least in some cases already do, have negative effects on the ecology of the Pine Barrens and coastal estuaries which rely in a variety of ways on the aquifer.

The completion and imminent publication of the Kirkwood-Cohansey Aquifer Study ("K-C Study") carried out by the US Geological Survey, the Pinelands Commission, DEP, Rutgers University researchers and the U.S. Fish and Wildlife Service, will provide a rigorous scientific basis for our conversation. The first day of the Forum is focused on presentation of the K-C Study results by the study's authors.

In order to help motivate and structure this Forum, it is important to set out some of the "givens" that underlie this discussion:

1. Many communities and industries which currently rely, in part or in whole, on the Kirkwood-Cohansey and Atlantic City 800-Foot Sands aquifers will grow in future years. This growth will increase the demand for water in the coming years.

2. Many habitats and plant and wildlife communities rely on the Kirkwood-Cohansey aquifer system for their survival and can be harmed by loss of stream flow and/or a drop in the water table.

    a. Withdrawals from the Kirkwood-Cohansey aquifer system can have measurable impacts on surface waters and the water table in or adjacent to the sub-watershed in which wells are located.

    b. Cumulative withdrawals from the Kirkwood-Cohansey and Atlantic City 800-Foot Sands aquifers can have impacts on surface waters and the water table, and on the fresh water/salt water boundary.

    c. These impacts can in turn affect the plant and animal communities which rely upon or are affected by surface water flows or the level of the water table, and on the productivity of wells.

    d. These impacts will and should be focused in the development areas where the water is to be used.

3. DEP and the Pinelands Commission will adopt policies that ensure that Pinelands and non-Pinelands growth areas are served with water sufficient to support the level of growth permitted by the Pinelands Comprehensive Management Plan (CMP) and other state and local land use plans.

4. As a surficial aquifer, the Kirkwood-Cohansey is susceptible to both natural and manmade contamination, such as radium and excessive nitrogen. As a result, the Department of Environmental Protection considers the Kirkwood-Cohansey to contain "water of lesser quality."

5. Policies of DEP and the Pinelands Commission should be framed to ensure that new or increased withdrawals:

    a. Are located with respect to the choice of water source, and the location and size of any wells, to avoid (or, perhaps, minimize) loss of native plant and animal communities (such as the alteration of one wetland type into another wetland or non-wetland habitat type) or the rare plant populations.

    b. Minimize the use of the Kirkwood-Cohansey aquifer system.

    c. Minimize or avoid conflicts among users and uses over limited water resources.

    d. Promote use of a range of water conservation measures.

    e. Manage the cumulative impacts of all withdrawals – including residential, agricultural, commercial, and industrial – affecting each watershed.

II. Basic Facts About the Kirkwood-Cohansey Aquifer

The Kirkwood-Cohansey is a surficial aquifer embedded in the sands that make up the surface geology of New Jersey's outer coastal plain. (Map 1, included in the attachments to this briefing paper) It forms the water table in this region and supplies nearly all the water that sustains the region's rivers, streams and wetlands. Because it includes multiple layers of relatively permeable formations, it is sometimes called the Kirkwood-Cohansey aquifer *system*. The aquifer covers over 1.9 million acres.

It is now recognized that well withdrawals from water table aquifers such as the Kirkwood-Cohansey aquifer have impacts to stream flow similar to those of direct surface water withdrawals. Kirkwood-Cohansey withdrawals "intercept" ground water that would otherwise discharge to a stream. During periods of low rainfall, these withdrawals can actually "pirate" flow from a stream, reversing the flow and drawing water out of the stream into the aquifer. Many water resource professionals believe that there is a one-to-one relationship: for every gallon of water withdrawn from a water table aquifer (and not returned), there is a gallon of water not available in the nearby stream or wetlands.

The New Jersey Pinelands is a region of approximately 1.1 million acres defined by federal and state legislation enacted to protect the unique ecological values and water resources on a regional scale. The legislation created a Pinelands Commission, and directed the Commission to adopt a Comprehensive Management Plan (CMP) to manage development throughout the region. The Pinelands National Reserve covers much, but by no means all of the extent of the Kirkwood-Cohansey Aquifer. Just over 1.1 million acres of the Kirkwood-Cohansey lies within the boundaries of the Pinelands National Reserve. (Map 1) While much of the Pinelands portion of the aquifer has been protected through land conservation and the CMP, some portions of the aquifer's area have been intensively developed. (Map 2)

The Pinelands Commission has placed a high value on the Kirkwood-Cohansey aquifer system since the Commission's inception. The Pinelands Comprehensive Management Plan (CMP) permits diversions from the Kirkwood-Cohansey system only for agriculture, or where there is no alternative source and it is demonstrated that no adverse ecological impact will occur as a result of the diversion. When water is obtained from the Kirkwood-Cohansey aquifer, the Commission has also acted to control transfers of water between watersheds from water supply distribution and/or centralized wastewater systems. In addition, State legislation (N.J.S.A. 58:1A-7.1) prohibits the exportation of surface and groundwater beyond ten miles from the boundary of the Pinelands National Reserve.

The Pinelands Commission's concern with the Kirkwood-Cohansey system is amply justified. Since the shallow aquifer provides from 80 to 95 percent of baseflow to streams and associated wetlands within the Pinelands, removal and distribution of water from this aquifer is of particular concern so as not to reduce streamflow and negatively impact wetlands and aquatic species.

III. The Kirkwood-Cohansey Aquifer Study and Why It Was Needed

In 2001, the State provided $5.5 million in funding through the "Gibson Bill," N.J.P.L. 2001 c. 165, to study the aquifer, and the federal government subsequently provided additional funds to the project. The legislation directed the Pinelands Commission, in cooperation with the United States Geological Survey (USGS), Rutgers University, the DEP, and the US Fish and Wildlife Service, to:

> "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 Kirkwood-Cohansey Study (K-C Study) seeks to address 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? A work plan for the aquifer assessment was prepared by the cooperating agencies, underwent outside peer-review, and was approved by the Commission in October 2003. Various elements of this work will be presented and discussed as the basis for this Science-Policy Forum.

The K-C Study came about in response to two growing concerns: the increasing demand for water to serve growth in South Jersey, and the recognition that while the Kirkwood-Cohansey is a readily available source to help meet this demand, it is also critical to the surface ecology of the region.

The Kirkwood-Cohansey is extensively exploited as a source of water for various human uses. In 2009, there were almost 3,000 wells (not including private domestic wells) withdrawing a total of more than 125 million gallons per day for public water supply, industrial, irrigation and other uses. Maps 3 and 4 show Public Supply and Irrigation Wells, respectively in the Kirkwood-Cohansey. About 1 million South Jersey residents rely in whole or part on the Kirkwood-Cohansey for their drinking water and other and home uses. The following table, from data tracked by USGS, summarizes the 2009 withdrawals by use:

Use	Number of Wells	Actual 2009 Total Volume (thousand gpd)	Percent of Total Withdrawals	Median Volume (thousand gpd)	Average Volume (thousand gpd)	Highest Volume Well (thousand gpd)
Public Supply	538	56,252	58%	16	163	1,883
Irrigation	1890	27,669	28%	7	18	394
Industrial	142	6,624	7%	8	71	1,094
Institutional	147	1,308	1%	2	11	237
Commercial	84	564	1%	2	8	103
Other Uses	175	5,048	5%	5	44	1,004
Total	**2,976**	**97,464**	**100%**			

Several findings and episodes illustrate the vulnerability of the Kirkwood-Cohansey and associated habitats to excessive or poorly-located wells and, therefore, the importance of obtaining a rigorous scientific study of the hydrology of the aquifer and impacts of withdrawals on the natural communities with rely on the aquifer. The following is an illustrative sample:

- During 1984 the Pinelands Commission convened a meeting among a group of scientists and the New Jersey Department of Environmental Protection to discuss potential impacts of exporting groundwater from the Pinelands to serve the metropolitan Camden area. Several issues were raised by the group. These were related to withdrawal induced changes in water quality, regional and local surface and ground water flow patterns, and the ecological implications of these changes. It was determined that if groundwater was to be exported out of the Pinelands to serve the Camden area, an intensive study would be necessary to quantify the impacts to the ecosystem from groundwater withdrawals (Pinelands Commission, October 1984).

- In Berlin Township, Camden County, approval for a municipal water supply well was rescinded when it was determined that withdrawals from the Kirkwood-Cohansey aquifer was impacting Swamp Pink, a plant that is federally listed as threatened pursuant to the Endangered Species Act. In addition, the New Jersey Geological Survey determined that when the well was in operation, a nearby stream that supports wetlands functions goes from a gaining stream, to a losing stream. (Water Allocation Permit Modification, Berlin Borough, January 2004)

- The Pinelands Commission found that the use of the Kirkwood-Cohansey aquifer to supply water for projected buildout of the Regional Growth Areas in Hamilton Township and portions of Galloway Township would significantly deplete stream flows, if wastewater was also exported out of the area via sewers (Pinelands Commission, August 1990)

- During 2003, a private water company's request for a 20 percent increase in allocation from the Kirkwood-Cohansey aquifer was thwarted when it was determined that there would be a loss of stream flow, and associated impacts to Knieskern's beaked-rush, a Federal and New Jersey listed threatened wetlands plant. Seeing no alternative, the water company installed a new well to a depth of 1225 feet in a deeper aquifer. (Water Allocation Permit Modification, Crestwood Village Water Company, April 2006)

- In February 1987, the Camden County Municipal Utilities Authority prepared a 208 water quality management plan for Chesilhurst Borough, Waterford Township, and Winslow Township. The proposal called for the transfer of sewage from the Regional Growth Areas of these Pinelands townships, to the Delaware Basin. It was determined that if the Kirkwood-Cohansey aquifer was used for water supply, the interbasin transfer of all of the wastewater to the Delaware River Basin would impact the flow of streams entering Wharton State Forest (Pinelands Commission, May 1988).

IV. Current Regulations and Status of the New Jersey Statewide Water Supply Plan

Existing regulations of DEP and, for wells inside the Pinelands, provisions of the Pinelands CMP, regulate new or increased "allocations" of water from the Kirkwood-Cohansey and other aquifers. By statute, DEP's allocation rules apply only to wells capable of pumping 100,000 gpd or more, so these rules do not limit the drilling of smaller wells typically used for agricultural irrigation and by some homeowners for their own use. The following summaries existing DEP and Pinelands Commission rules.

A. Pinelands CMP:

1. Water management standards, NJAC 7:50-6.86 (http://www.state.nj.us/pinelands/cmp/CMP.pdf)

   (a) Interbasin transfer of water between watersheds in the Pinelands should be avoided to the maximum extent practical. In areas served by central sewers, water-saving devices such as water-saving toilets, showers and sink faucets shall be installed in all new development.

   (b) Water shall not be exported from the Pinelands except as otherwise provided in NJSA. 58:1A-7.1.

   (c) All wells and all increases in diversion from existing wells which require water allocation permits from the Department of Environmental Protection shall be designed and located so as to minimize impacts on wetlands and surface waters. Hydrologic analyses shall be conducted in accordance with the New Jersey Department of Environmental Protection and Energy Guidelines for Water Allocation Permits, with an Appendix on Aquifer-Test Analysis Procedures, New Jersey Geological Survey Report GSR 29, 1992, incorporated herein by reference, as contained in pages 53 through 91 of the Technical Manual for Water Supply Element, Bureau of Water Allocation, Water Allocation Permits dated May 19, 1993, as amended.

   (d) All applications for the development of water supply wells or the expansion of existing water distribution systems shall address measures in place or to be taken to increase water conservation in all areas to be served by the proposed well or system. This shall include efforts by water purveyors and local governments to reduce water demands by users and to reduce losses in the supply and distribution system.

   (e) Except for agricultural uses, all new potable and non-potable water supply diversions of more than 100,000 gallons per day that utilize the Kirkwood-Cohansey aquifer as a source of water supply and new increases in existing potable and non-potable water supply diversions of over 100,000 gallons per day that utilize the Kirkwood-Cohansey aquifer may be permitted only if it is demonstrated that:

      1. No viable alternative water supply sources are available; or

      2. The proposed use of the Kirkwood-Cohansey aquifer will not result in any adverse ecological impact on the Pinelands Area.

2. No development is permitted unless it is designed to avoid irreversible adverse impacts on the survival of any local populations of plants designated endangered by DEP and those listed in the rule. NJAC 7:50-9.27(a).

3. No development is permitted unless it is designed to avoid irreversible adverse impacts on habitats that are critical to the survival of any local populations of threatened or endangered wildlife. NJAC 7:50-6.33.

B. DEP rules:

Under the Water Supply Management Act regulations, NJAC 7:19-2.2(f), (http://www.nj.gov/dep/watersupply/NJAC7_19.pdf) DEP requires applicants for water allocation permits to show:

1. That the proposed diversion is in the public interest;

2. That the diversion shall not exceed the natural replenishment or safe yield of the water resources or threaten to exhaust such waters or to render them unfit for use;

3. That the plans for the proposed diversion are just and equitable to the other water users affected thereby, and that the withdrawal does not adversely affect other existing withdrawals, either ground or surface;

4. That, in the case of a ground water diversion, the proposed diversion will not cause an increase in saline intrusion that renders the water resource unfit for use; will not spread ground water contamination; and will not interfere with any ground water remediation plan or activity;

C. DEP's State Water Supply Master Plan:

The New Jersey Water Supply Management Act (N.J.S.A. 58:1A-1 et seq. - http://www.nj.gov/dep/watersupply/njsa_58_1a_1.pdf) prescribes that DEP develop and periodically update the New Jersey Statewide Water Supply Plan.

1. **1996 Plan:** The last comprehensive plan was developed in 1996. A major objective of this plan was to quantify the status of the water supply of each of the 23 major watersheds in the state.

   The plan estimated the amount of water that was withdrawn from each watershed in an effort to determine if there was sufficient remaining water to support future water supply withdrawals, suitable water quality, protect and maintain aquatic resources, and defer saltwater intrusion. If a watershed had ample remaining water to maintain these uses, that watershed was concluded to be in "surplus." If a watershed did not possess ample water to maintain these uses, that watershed was concluded to be in "deficit." DEP also projected water demand out to the year 2040 to estimate the surplus or deficit condition of these watersheds.

   Ten of 23 of the largest watersheds in the state are wholly or partially within the Pinelands Comprehensive Management Plan area. Five of the watersheds were found to be in current deficit, and two additional watersheds were projected to be in deficit by

the year 2040. This plan did not make a distinction of whether demand was within or outside of the Pinelands area when assessing surplus or deficit conditions.

In general, deficits in watersheds that had large population centers were caused by excessive purveyor demand, while deficits in watersheds that had large farming operations were caused by excessive agricultural demand. In many watersheds, deficits were the result of both concentrated purveyor and agricultural demands. The watersheds with the greatest deficits are the Camden-Delaware Tributaries, Mullica River, Toms River watersheds, followed by smaller deficits in the Maurice River and Metedeconk River watersheds. Year 2040 deficits are projected in the Cape May and Atlantic Coastal watersheds.

2. **Current Plan:** The most recent New Jersey Statewide Water Supply Plan has been drafted, but has not yet been formally released. To more accurately identify existing and potential water supply concerns, this document evaluated the 151 smaller watersheds of the state, employed a more comprehensive quantification of demand and the nature of the demand, and used a more precise analytical tool to estimate the status of these watersheds. Many HUC11 watersheds within the Pinelands area are stressed.

V. The Kirkwood-Cohansey Study In Brief

The Kirkwood-Cohansey Study (K-C Study) forms the key scientific basis and motivation for this Forum. Most elements of the Study have been published and can be accessed via the hyperlinks in the References section at the end of the briefing paper.

The first day of the Forum will be devoted to presentations by the authors and group discussion of the Study's methods and results. This briefing material provides a very summary overview of the Study's key elements:

1. Hydrological Modeling and Findings
2. Ecological Impact Studies
3. Landscape-level Modeling of the Impacts of Withdrawals
4. Built-out Analysis

1. Hydrologic Modeling and Findings

This summary of the hydrologic effects of groundwater withdrawals from the Kirkwood-Cohansey aquifer system in the New Jersey Pinelands was prepared by Robert S. Nicholson and Emmanuel G. Charles of the U.S. Geological Survey, New Jersey Water Science Center

Overview: The U.S. Geological Survey (USGS), in cooperation with the New Jersey Pinelands Commission, conducted a multi-phase investigation to characterize the hydrologic system that supports aquatic and wetland communities of the Pinelands.

Initial phases of the investigation, conducted during 2004-2009, characterized the hydrology of three representative drainage basins: McDonalds Branch, Albertson Brook, and Morses Mill Stream. The investigation included an analysis of:

- the hydrogeologic framework of the Kirkwood-Cohansey aquifer system,
- water-level and streamflow variability,
- groundwater gradients and groundwater-flow patterns,
- evapotranspiration,
- water budgets,
- water-table depth, and
- water use.

Results of the hydrologic characterization and analysis were used to inform the development of predictive hydrologic models that were used to evaluate the hydrologic effects of groundwater withdrawals. Other project partners integrated results of the USGS modeling analysis with ecological models developed as parts of other elements of the Kirkwood-Cohansey Project to estimate ecological responses to hypothetical withdrawals.

Hydrogeologic Framework: The hydrogeologic framework of the three drainage basins was interpreted from geophysical and lithologic borehole data, ground-penetrating radar surface geophysical data, and data from previous investigations. The Kirkwood-Cohansey aquifer system was conceptualized as consisting of seven layers, defined by their predominant sediment textures as aquifers or leaky confining layers. Key aquifer-system characteristics are summarized below:

- Sediments of the Kirkwood-Cohansey aquifer system are mostly sand and gravel, with some finer sediments; the aquifer system is highly transmissive.
- The base of the aquifer system, depending on location, is defined by one of two distinct clays of the Kirkwood Formation.
- Clay layers within the aquifer system above the basal clays are discontinuous and variable in thickness, as confirmed by geophysical and lithologic records.

- Leaky confining layers and discontinuous clays are generally more common in the upper part of the aquifer system than in the lower part.

- Although the aquifer system is generally considered unconfined in most areas, localized clays impede the flow of ground water in some areas.

Hydrologic Assessment: Recharge replenishes the groundwater in the Kirkwood-Cohansey aquifer system and is the source of groundwater flow, most of which is toward natural discharge areas such as wetlands and other surface water features. Some groundwater flow is intercepted by supply wells, and some groundwater flows to deeper aquifers and coastal areas. Recharge rates are generally highest during the non-growing season when evapotranspiration is low. The shallow depth to the water table in wetland areas supports characteristic wetland-forest communities. The key findings of the hydrologic assessment can be summarized as follows:

- Analysis of subsurface hydraulic gradients, water-table fluctuations, streamflow variability, and results of aquifer tests indicates that groundwater and surface water (wetlands, lakes, and streams) are highly interconnected.

- Most wetlands are in groundwater discharge areas, but some wetlands are in groundwater recharge areas.

- Most discharge-area wetlands and surface water receive persistent regional groundwater flow, which continues to support the wetlands and surface water during dry periods.

- Recharge-area wetlands and nearby surface water do not receive regional flow and consequently are more sensitive than those in discharge areas to drought conditions.

- The water-budget analysis shows that the hydrologic system that supports wetland and aquatic habitats is dynamic and is sensitive to seasonal variations in components of the hydrologic budget.

- An aquifer test was conducted in each of the three drainage basins, in which groundwater was pumped from the aquifer system at a constant rate of 839 to 2,669 cubic meters per day (0.2-0.7 million gallons per day) for a period of 5 to 10 days. The maximum measured drawdown in shallow wetland observation wells during the aquifer tests ranged from 5.5 to 16.7 centimeters.

Hydrologic Modeling: Information from the hydrogeologic framework interpretation and the hydrologic assessment was used to develop detailed groundwater-flow models of the three basins. The models were calibrated to conditions observed during a 2-year period and during aquifer tests. The models were used to evaluate the sensitivity of hydrologic responses to well position, pumping rate, and well depth.

Results of the sensitivity analysis were used to formulate a series of hypothetical case studies of water withdrawals spatially distributed to result in "best-case" and "worst-case" hydrologic responses (with respect to drawdown and baseflow reduction) in each basin. The sum of the groundwater withdrawals represented in the simulations was equal to 5, 10, 15 and 30 percent of overall recharge.

A useful metric for evaluating and comparing changes in water-table depth is the percentage of the wetland area in a basin over which simulated water-level drawdown exceeds a particular threshold value, such as 15 cm. The following are the key findings determined from results the hydrologic modeling analysis:

- Groundwater withdrawals in a given basin will result in hydrologic effects in that basin and will also result in hydrologic effects in adjacent basins.
- Withdrawals equal to 5 percent of recharge resulted in the following effects:
    - Water-level decline exceeding 15 cm over as much as 1.5 percent of the total wetland area in the "best-case" simulations and as much as 10 percent of the total wetland area in the "worst-case" simulations.
    - Baseflow reduction as much as 5 percent in the "best-case" simulations and as much as 9 percent in the "worst-case" simulations.
- Withdrawals equal to 30 percent of recharge resulted in the following effects:
    - Water-level decline exceeding 15 cm over as much as 70 percent of the total wetland area in the "best-case" simulations and as much as 84 percent of the total wetland area in the "worst-case" simulation.
    - Baseflow reduction as much as 30 percent in the "best-case" simulations and as much as 51 percent in the "worst-case" simulations.
- Withdrawals equal to10 and 15 percent of recharge resulted in water-level decline and baseflow reductions that were intermediate between those simulated for withdrawals equal to 5 and 30 percent of recharge.

Applying Results in Other Areas: Approaches for applying results of the study to other parts of the Pinelands were explored, including the use of simpler analytical models and empirical methods. Results of this exploration indicate that simpler approaches can provide practical means to estimate hydrologic effects of withdrawals from the Kirkwood-Cohansey aquifer system in areas for which detailed models are not available. Results obtained by using simple models were similar to those obtained by using the more detailed models.

The simpler approaches could be used, with some limitations, to evaluate alternative water-supply strategies and, in conjunction with results of ecological modeling, determine maximum rates of withdrawals within the limits of acceptable ecological change.

2. Pinelands Commission Ecological Study

Introduction: The Pinelands Commission science program investigated the likely effects of groundwater withdrawal from the Kirkwood-Cohansey aquifer and resulting groundwater level reductions on several aspects of the Pinelands biota. The results are published in a series of reports listed in the References and available on the Pinelands Commission website. These reports employed simulations of groundwater drawdown to predict effects on Swamp Pink, three species of pond-breeding frogs, stream macroinvertebrates, coastal plain fish, intermittent pond vegetation, and forested wetland communities.

Swamp Pink: Measurements of site hydrology of existing Swamp Pink populations suggested an optimal water level range for this species. Simulated water-level drawdown at varying levels indicated that a relatively small drawdown of 15cm exposed more than 30% of Swamp Pink to extreme hydrologic conditions, and a larger drawdown of 30cm exposed all or nearly all of Swamp Pink cluster area to extreme conditions.

Pond-Breeding Frogs: At simulated groundwater drawdowns greater than 10cm, impacts to the metamorphosis of pond-breeding frogs (Southern Leopard Frog, Spring Peeper, and Pine Barrens Treefrog) occurred, with impacts to egg deposition resulting from a 20cm reduction. Water depth level reductions of 50cm were shown by simulations to shorten the hydroperiod enough to practically eliminate larval development and metamorphosis for all three frog species, with the greatest impacts to Pine Barrens Treefrog.

Pond Plant Communities: Effects of groundwater withdrawals and associated groundwater level reductions on intermittent pond plant communities were demonstrated by simulations of reduced water depth by 5cm intervals up to 50cm. Aquatic- and wetland-herbaceous vegetation patch types were the most sensitive to simulated drawdowns and were reduced at even the smallest simulated reduction. Walter's Sedge community patches decreased steadily in area for drawdowns greater than 10cm. Leatherleaf patches and Highbush Blueberry patches showed variable responses. These results suggest that permanent water-level reductions due to groundwater withdrawals will lead to progressive change and, in the extreme case, replacement of intermittent pond vegetation with adjacent forest woody vegetation.

Aquatic Invertebrates and Fish: Streamflow reduction scenarios of 5, 10, 20, and 30 percent of average annual streamflow were simulated for their expected impacts on invertebrate and fish species diversity, with the following results:

- reduction in Pinelands aquatic-invertebrate taxa richness by 0.75% (with loss of 5% of average annual streamflow) to 5.7% (with 30% loss of average annual streamflow),
- reduction in coastal plain fish-species richness of 1.4% to 10.1%, and
- smaller streams are more vulnerable to species losses than larger streams.

Wetland Forests: A study of the hydrology of forested wetlands in the Pinelands informed models which can be used to predict changes in vegetation associated with groundwater-level declines. The hydrology of a gradient of wetland to upland vegetation community types was assessed: cedar swamp, hardwood swamp, pine-hardwood lowland, pitch pine lowland, and pine-oak upland. The results of this study can be used to predict changes in the vegetation community type resulting from

groundwater withdrawals, with the more xeric pine-oak uplands and pitch pine lowlands likely to develop on sites in which groundwater levels are reduced, replacing the wetter cedar swamps, hardwood swamps, and pine-hardwood lowlands.

Key indicators of groundwater changes in Pinelands Commission studies: The indicator species and communities used for this study are:

Species:

Swamp Pink *(Helonias bullata*)

Southern Leopard Frog *(Lithobates sphenocephalus)*

Spring Peeper *(Pseudacris crucifer)*

Pine Barrens Treefrog *(Hyla andersonii)*

Walter's Sedge *(Carex striata)*

Leatherleaf *(Chamaedaphne calyculata)*

Highbush Blueberry *(Vaccinium corymbosum)*

Communities:

Stream aquatic invertebrates

Coastal Plain fish

Atlantic White Cedar Swamp

Hardwood Swamp

Pine-Hardwood Lowland

Pitch Pine Lowland

Aquatic Herbaceous Zone

Wetland Herbaceous Zone

3. Landscape Level Modeling

This briefing paper is a highly condensed report based on Landscape Level Modeling of the Potential Effect of Groundwater-level Declines on Forested Wetlands in the New Jersey Pinelands, by Lathrop, R., Y. Zhang, Z. Maio & J. Bognar (September 2010).

This element of the K-C Study models the effects on vegetation of potential declines of groundwater due to well pumping. The study Combines (a) the Pinelands Commission science program's modeling of the effects water table change on wetland forest types and species composition, with (b) the USGS modeling of the impacts of various water withdrawal scenarios on the water table in three study basins (McDonalds Branch, Albertson Branch, and Morses Mill Stream).

The study calculates and uses GIS to map the vegetation changes, as compared to the existing baseline situation, expected to occur under each of the following water withdrawal scenarios in each study basin:

Well located *far* from wetlands ("Best case")

5% of current recharge volume

10%

15%

30%

Well located *near* wetlands ("Worst case")

5% of current recharge volume

10%

15%

30%

Each basin is divided into 10 m^2 grids to characterize existing vegetation and calculate changes to three different measures:

a. percent of wetland indicator plants (vs. non-wetlands species);

b. probability of occurrence of specified forest (or "woody vegetation") types – i.e., cedar swamp, hardwood swamp, pine-hardwood lowland, pitch pine lowland, or pine-oak upland; and

c. dominant forest type.

The study did these calculations and maps for those cells in which the USGS modeling showed the existing, baseline depth to water table to be between 2 cm and 200 cm.

Key results, in simplified form, are:

1. All scenarios show lowering of the water table and significant loss and fragmentation of wetlands vegetation and forest types.

2. The greater the percent of recharge pumped, the greater the resulting change.

3. At the higher levels of groundwater withdrawal the decline of wetland area will be especially severe in the upper headwaters of the basins, and that there will be 'retreat' of existing wetlands to a narrower streamside corridor.

4. Cedar and hardwood swamps were the most sensitive to water table change.

5. Even the 5% of recharge scenario showed major loss (e.g., 50% of cedar swamp) and fragmentation in one of the basins, and substantial loss (e.g., 10-15% of cedar swamp) in the other two.

6. Location of wells made no significant difference in two of the three basins. Location made a bigger difference in one of the basins, but even there the amount of pumping was the critical driver of the degree of impact.

7. The basins showed some differences in their sensitivity to withdrawals, so degree of impact will vary with the topography and hydrology of each basin.

4. Pinelands Commission Buildout - Water Demand Analysis Study

This summary was prepared by Larry Liggett of the Pinelands Commission staff.

The first component of this Study was to inventory and gather the available geographic and tabular data related to water consumption, water loss, land use, infrastructure and population and economic projections. After assessing the available data and determining data gaps, the Planning staff of the Pinelands Commission's Land Use and Technology Programs department developed model assumptions for calculating current water use for residential, non-residential and agricultural water users. An accurate baseline estimate of **current water demand** was imperative for the needs of this Study; the baseline estimates plus future growth together represent the total load being placed on the aquifer. Additionally, Commission staff gathered and analyzed information to better understand the water conveyance system (both water supply and wastewater). This information was used to determine the current impact (consumptive and depletive uses) on the Kirkwood-Cohansey Aquifer.

The Geographic Information Systems staff of the Land Use and Technology Programs department created a comprehensive, parcel-based data layer for the entire Pinelands Area to populate the development status of each parcel. All public lands were identified, and private lands were categorized as vacant, fully developed or developed, not to full potential. Both GIS and Planning staff collaborated to develop a methodology for determining the amount of developable land and at what intensity that land would likely be developed. The methodology was used to create GIS models to calculate additional development generated in **three build-out scenarios** (higher, medium, and lower).

Finally, the estimates developed in the current water-use calculations were carried over, or modified where needed, to calculate **future water demands**. The results of the current and future water use calculations were analyzed together and will be used as a tool to assist planning efforts in the Pinelands Area. By analyzing the location and size of current wells in relation to future demand, planners can estimate where and how many future wells may be needed. Ecological data generated from the other components of the Study will further assist planners place wells in areas where adverse impacts will be eliminated or minimized, while at the same time serving the future needs of the community.

The term “Build-Out,” also known as “land supply and capacity analysis”, is a planning term used to describe a methodology that can estimate the maximum amount of development that will occur in an area based upon the characteristics and the regulations that govern that land. Its purpose is to provide the information for future long-term planning/decision making by supplying the amount (e.g., dwelling units, square footage, and acres irrigated) and location of new development relative to a particular area (Lathrop, 2001 Barnegat). In recent years, calculating new development has become increasingly more realistic, mainly due to parcel-based geographic information systems data (Monitoring Land Supply, Moudon, Hubner, 2000). These parcel-data sets provide a view of property that is real. By using this information, an analyst can build a model that will closely emulate the development/subdivision process. However, even with the most detailed geographic data, most build-out models are limited in their ability to predict when development will take place and how consumer preferences will affect the housing and non-residential markets and, in turn, the resulting land use patterns.

The build-out analyses in this study did not seek to predict the demand for residential units or non-residential square footage, but predicted the end-point number of residential units and non-residential square footage based upon the regulatory frameworks in place as of July 2004 on a parcel by parcel basis. The purpose of the Study was to provide the demand (housing units or non-residential

square footage) for water withdrawal from the Kirkwood-Cohansey aquifer when various build-out scenarios occur at some time in the future. The focus of the agricultural build-out section is to assess the future of agriculture in the region and the likely water-use demands placed on the aquifer as a result of this demand.

VI. Water Supply Alternatives

This section was created by Robert Kecskes, retired water supply planner with the DEP.

Protecting the ecological integrity of surface waters while serving human needs throughout the region may require state regulators and water purveyors to use water supply alternatives in addition to or instead of simply pumping water from aquifers like the Kirkwood-Cohansey for distribution through existing systems. Among alternatives DEP, the Pinelands Commission and purveyors may consider are:

a. Conjunctive Use of Kirkwood-Cohansey Aquifer and Other Source Supplies

This alternative requires the user of the Kirkwood-Cohansey aquifer supply to cease withdrawals and turn to another source supply when stream flow/wetlands near the threshold. Other source supplies can be from the confined aquifers in the immediate area (if available) or from other watersheds that have ample supplies of water. Use of confined aquifers would be evaluated to ensure that the alternative does not aggravate saltwater intrusion, or cause excessive stream flow depletion and/or wetlands dewatering. This alternative should be evaluated at a regional level.

b. Conjunctive Use of Kirkwood-Cohansey Aquifer and Stored Surface Water Supplies

Water stored in ponds or reservoirs represents another source of water in situations where the Kirkwood-Cohansey aquifer is unavailable, such as when low flows would exceed regulatory thresholds. These supplies would be withdrawn from either the Kirkwood-Cohansey aquifer or directly from nearby streams or rivers and placed into lined ponds or reservoirs during periods of higher flows for use when needed to avoid exceeding low flow thresholds.

c. Conjunctive Use of Kirkwood-Cohansey Aquifer and Stored Ground Water Supplies

Water stored in confined aquifers represents another source that could be used when the Kirkwood-Cohansey aquifer is unavailable. Similar to the alternative discussed above, these supplies would be withdrawn from either the Kirkwood-Cohansey aquifer or directly from nearby streams or rivers and injected into a confined aquifer during periods of higher flows, and placed into use when the thresholds occurred. Either a fresh water or brackish water confined aquifer can be used for storage. If a brackish aquifer is employed, significantly larger amounts of Kirkwood-Cohansey aquifer or river water would need to be injected to ensure that brackish water in the confined aquifer does not make its way into the water supply.

d. Conjunctive Use of Two or More Kirkwood-Cohansey Aquifer Wells

This alternative requires the user of the Kirkwood-Cohansey aquifer supply well near a stream to cease withdrawals when stream flow/wetlands nears the threshold, and turn to another Kirkwood-Cohansey aquifer well that is a further distance from the stream to ensure that that the flow/wetlands would remain un-impacted during periods of low rainfall.

e. Recycling Alternative – Public Water and Sewers

This alternative would be employed in Pineland growth areas. It consists of withdrawal(s) from Kirkwood-Cohansey aquifer wells that are located in the same vicinity as the wastewater discharge(s) to surface or ground water to reduce the effects of stream flow depletion and/or wetlands dewatering. Water is withdrawn from Kirkwood-Cohansey aquifer wells, used in homes and businesses, treated to high levels at a local wastewater plant, and discharged to the stream and/or wetlands that are affected by the withdrawals. Water conservation would be required in order to ensure that discharge is approximately equal to withdrawals. This alternative is not currently allowed by the Pinelands Commission; consequently, revisions to the Pinelands regulations would be required to implement it.

f. Recycling Alternative – Private Well and Septic Systems

This alternative would be employed in low-density growth areas of the Pinelands. It consists of withdrawal(s) from private Kirkwood-Cohansey Aquifer wells on large lots and wastewater discharged to private septic systems in the Cohansey aquifer to reduce the effects of stream flow depletion and/or wetlands dewatering. Water conservation required in order to ensure that discharge is approximately equal to withdrawals. It should also be managed by responsible entity to ensure homeowners maintain their septic systems and do not contaminate the aquifer. This alternative is Ideal for areas outside of Pinelands growth areas, but within areas where low density development, especially under a Transfer of Development Rights scheme.

g. Reclaimed Water Alternative

This alternative would consist of withdrawal(s) from Kirkwood-Cohansey aquifer wells that are supplemented by reclaimed water from a nearby wastewater treatment plant. Reclaimed water would be used for non-potable uses such as residential and agricultural irrigation, energy production, etc. It would be used only when aquifer wells will not "compromise" the stream flow and/or wetlands threshold.

h. Desalination Alternative

This alternative would require the entity (purveyor, municipality, etc.) to cease using primary Kirkwood-Cohansey aquifer supply and turns to salty/brackish confined aquifer when stream flow/wetlands nears the threshold. Salty/brackish water from confined aquifer would be treated at a desalination plant. Confined aquifer wells can be in the immediate area (if available) of the Kirkwood-Cohansey aquifer wells. This alternative must assess whether pumping of the confined aquifer could affect other users or cause environmental problems.

i. Water Conservation Alternative

This alternative would consist of a strategic water conservation plan that is implemented for users of the Kirkwood-Cohansey Aquifer to ensure that stream flow depletion and/or wetland dewatering thresholds are maintained. To achieve this purpose, conservation measures would need to be implemented for users of the wells affecting a stressed

watershed, although those users will in most cases include homes, businesses and institutions located outside the affected watershed. Such a plan could include any or all of a range of conservation measures:

- Audit current water uses and distribution system, water losses, and recycling options affecting the watershed.
- Limit use and type of irrigation, especially by homeowners, commercial properties, and public institutions, by controlling frequency and timing of irrigation and requiring best practices such as use of rain gauges.
- Reduce managed turf areas that require intensive irrigation.
- Fund installation of efficient agricultural irrigation practices, such as conversion to drip irrigation.
- Capture unaccounted-for water by repairing leaking distribution systems, identifying defective or by-passed meters, and so on.
- Fund innovative metering strategies that encourage conservation.
- Convert/retrofit residences, businesses, schools and other public buildings to use low-flow toilets and efficient appliances.
- Implement pricing structures that encourage conservation.
- Work with major commercial or industrial users to identify and implement efficiencies tailored to each business.

VII. Policy Questions and Options for Discussion

The discussion at the second day of the Forum will center on a series of policy options ("POs" in this paper) to address key policy questions. The following summarizes the questions and policy options we will discuss. During the discussion, participants will have the opportunity to suggest additional policy options in response to each basic policy question.

We aim to have this discussion be guided by the results of the Kirkwood-Cohansey Aquifer Study ("K-C Study") presented on the first day of the Forum.

The basic policy questions have been chosen to make the agenda manageable and to focus on the most important issues DEP and the Pinelands Commission face in creating rules and plans that will ensure the sustainability of the Kirkwood-Cohansey aquifer. They are not exhaustive and do not capture all the technical issues that will have to be resolved in finalizing new standards or plans.

During the policy discussion, participants will be polled on each policy option and asked to respond via anonymous keypad polling with one of the following responses:

Agree, and this policy option is a high priority

Agree, but this policy option is a low priority

Agree in theory, but this option is not possible or practical

Disagree, because this option is a bad idea or not an effective solution

I. Rules for Controlling Impacts of New or Increased Allocations

DEP and, in the Pinelands Area, the Pinelands Commission review applications for new or increased allocations of water against each agency's regulatory criteria. We will discuss new options for what these criteria should be for the Kirkwood-Cohansey aquifer.

Question A: *What criteria should be used in judging acceptable vs. unacceptable impacts of each application for a new or increased allocation from the Kirkwood-Cohansey aquifer?*

The assumed goal of setting a regulatory criterion is to ensure that withdrawals are only approved if they are compatible with maintaining the ecology which depends upon the aquifer. The policy options present different ways of viewing and answering this general goal. (Water regulations may also have additional goals, like protecting the productivity of preexisting wells in the area.)

The results of the K-C Study indicate that withdrawals affect streams and rivers differently from wetlands (swamps, bogs, and savannahs), so the permit criteria should be different for each if the criteria are to manage these impacts.

Question A1: *For impacts to streams and rivers, what criteria should be used in judging acceptable vs. unacceptable impacts of each application for a new or increased allocation from the Kirkwood-Cohansey aquifer?*

We will consider five possible criteria for regulating the amount of water a well may be permitted to withdraw based on its expected impact on nearby streams. These criteria can be applied both to direct withdrawals from streams and to indirect withdrawals through pumping from the aquifer via a well. In the case of wells, the criteria are based on the assumption that water withdrawn from the aquifer is also withdrawn from the stream which the aquifer feeds in that area.

We will consider these possible criteria:

- ***PO1*** Low Flow Margin – Allow removal of a percentage of median September flow minus 7Q10 flow.
- ***PO2*** Percent of 7Q10 – Allow removal of a percentage of the 7Q10 flow.
- ***PO3*** Percent of Drought of Record – Allow removal of a percentage of the drought of record flow.
- ***PO4*** Ecological Passing Flow– Allow withdrawal up to the a passing flow set to protect native ecological functions.
- ***PO5*** Combination – Allow the use of Low Flow Margin, Percent of 7Q10 or Percent of Drought of Record, but with the Passing Flow Requirement as a floor or limit in all cases.

Definitions of each of these criteria follow, together with charts (attachments to this briefing paper) which seek to illustrate what these criteria mean and to clarify their differences:

7Q10: Two of these criteria rely on the concept of "7Q10," which is defined as the lowest 7-day average flow that occurs every 10 years. The 7Q10 is specific to each stream, and to each segment of a stream. It is calculated based on actual historic stream flow data and may change due to human or natural events over time.

> The 7Q10 criterion was developed to maintain water quality to support human uses and is not based on an analysis of how much water is needed to sustain aquatic wildlife or plants or other ecosystem functions. (E.g., Hoffman and Rancan 2009, p. 3)
>
> 7Q10 is not the same as "drought" flow, because droughts are more extreme conditions, occurring over a longer period of time (a year or many years) than 7Q10 flows. In addition, droughts are natural phenomena, while the 7Q10 for a stream is determined by the combination of natural hydrology and human impacts, such as withdrawals. (EPA Flow 101)

PO1 – Low Flow Margin: This criterion aims to ensure that withdrawals do not cause stream flows to reach or exceed a "low flow" threshold, usually defined as the 7Q10 flow. Low Flow Margin seeks to achieve this result by permitting withdrawals of only a portion, say 25% or 50%, of the volume of water *above* the 7Q10 that is in the stream in September,

typically our driest month. The percentage restriction provides a margin of safety (you can't take all the available water above the 7Q10 level). By this means, low Flow Margin seeks to ensure there is always enough water in the stream to support fish communities and other ecological functions.

PO2 – Percent of 7Q10: This criterion would allow a user to withdraw a fixed percentage, such as 25% or 50%, of the 7Q10 at all times, regardless of the actual amount of water in the stream. This criterion limits withdrawals when water is plentiful, but also permits withdrawals to continue even in dry conditions in which the withdrawal would deplete the stream below the 7Q10 or other threshold so long as the well continues to produce. This criterion, then, might be considered highly protective in times of plenty and not at all protective in times of want.

PO3 – Percent of Drought of Record: This criterion operates on the same principal as the percent of 7Q10, but instead permits withdrawals of a percent of the flow during the drought of record. For the same percentage, such as 25% or 50%, this criterion would be more protective of flows than percent of 7Q10 in most situations, since the 7Q10 should generally be greater than the drought of record flow.

PO4 – Ecological Passing Flow Requirement: An ecological, seasonal passing flow requirement aims to establish and protect the minimum stream flow required to sustain native ecological functions, including wildlife and plant communities, of the stream. A passing flow requirement will set different minimum volumes that must be maintained at all times, including drought, by all those withdrawing water, tailored to the ecology of the stream – or stream segment – such as the wildlife that relies on the stream.

> Historically, DEP has specified "passing flows" in a variety of ways not necessarily based on ecological needs, sometimes using the 7Q10 or other statistical treatment of historic flows, and has applied set a single passing flow amount that applies year round of season or how much water is recharging the stream. The policy option here would replace these practices with use of an ecological passing flow calculation tailored to the minimum ecological requirements of each stream.
>
> DEP has recently begun exploring ways to implement an ecological passing flow threshold based on the Hydroecological Integrity Process (HIP) developed in cooperation with the US Geological Survey. (Hoffman and Rancan 2009)

PO5 – Combination Using Ecological Passing Flow as Limit on Withdrawals: This approach would use one of the first three criteria up to the point at which withdrawals would violate the Passing Flow Requirement due to drought or other periodic conditions. At that point, the Passing Flow Requirement would apply in order to avoid human uses inducing the stream flow to fall below the flow needed for ecological functions. If all wells were tied to this standard as a floor below which withdrawals may not induce the stream to go, then this standard could ensure that flows below the ecological passing flow were very rare and induced only by natural climate cycles.

In order to simplify the discussion, these policy options do not specify the percentage of flow used in PO1, PO2 and PO3. The goal is to focus discussion on the basic approach to setting the regulatory criteria, not to get lost in technical debate over exactly where the bar in each case would be set.

Each of these potential criteria would place a different limit or threshold on the impact of a proposed withdrawal. The differences are best shown graphically, and we provide three charts to illustrate these issues based on historic data for one Pine Barrens stream, the Tuckahoe River. These charts can be found at the back of this briefing material. They are:

Chart 1: Shows actual stream flows for the Tuckahoe River at the head of tide during the period December 1969 to February 2012. This Chart provides a feel for the great natural variability of Pine Barrens river flows.

The Tuckahoe River's 31 square mile watershed is located between Cape May and Atlantic Counties and does not currently have significant withdrawals from its surface and ground waters. Since withdrawals in this watershed are not substantial, the flows shown in Chart 1 may be considered effectively "natural." As shown, the vast majority of flows in the Tuckahoe River at this location are less than approximately 25 million gallons a day.

Chart 1A: This is the same as Chart 1 but using a logarithmic scale of flows, allowing us to display the September Median, 7Q10 and Drought of Record flows.

Chart 2: This is the same as Chart 1 but cutting off the high end of flows at 20 mgd, allowing us to display the September Median, 7Q10 and Drought of Record flows in relation to the lower flow levels the river has seen during this period.

Chart 3: This is a hypothetical hydrograph, based closely on the Tuckahoe River flows in the drought year of 2000, with the results for stream flow of each of five potential regulatory criteria above. This chart compares the natural stream flow to the flow resulting from withdrawals up to an amount permitted by each criterion, together with the September Median, 7Q10 and Drought of Record flows. The hypothetical net flows are based on the assumption that wells are limited to withdraws of 50% of the low flow margin, 7Q10, or drought of record flows.

We have also added a red line showing how much water a purveyor might be permitted to withdraw through the year using an Ecological Passing Flow as the floor on withdrawals.

Water supply planning typically focuses on flows that can be expected during drought, because we expect ecological impacts to be greatest when induced flows are lowest during drought periods. As shown in Chart 2, during the period 1969 to early this year the watershed experienced several droughts; in 1980 (one of the worst droughts in New Jersey history), there was only approximately 840,000 gallons discharging from the river in September – the lowest flow on record or the "drought of record low flow." On at least six other occasions during the last 43 years, the river dipped below the seven consecutive day low flow for 10 years (7Q10).

The 7Q10 has a recurrence interval of 10%, or once in ten years. While the natural ecological resources of a stream have evolved to endure the 7Q10 flow on an infrequent basis, flows this low should not be prolonged for extended periods or increase in frequency.

Question A2: *For impacts to wetlands, what criteria should be used in judging acceptable vs. unacceptable impacts of each application for a new or increased allocation from the Kirkwood-Cohansey aquifer?*

The K-C Study found that wetlands are affected by lowering the water table, and that Kirkwood-Cohansey wells do lower the water table in their vicinity according to predictable patterns. These three policy options provide ways to limit or avoid such impacts, based on the Study findings of how water table reductions can be expected to affect various wetlands communities and indicator species.

We will discuss the following policy options for allocations affecting wetlands:

- ***PO6*** Generic – Allow a specified reduction (so many inches) in water table level in all type of wetlands.
- ***PO7*** Species-specific – Allow a specified reduction in water table level, with the permitted reduction varying with the indicator species and communities in the K-C Study, particularly wetland forest type, Swamp Pink, and Pine Barrens Treefrog.
- ***PO8*** Pinelands pond-specific – Allow a lesser, more restrictive reduction in water table level where a Pinelands pond is present.

As outlined in the K-C Study summary in these briefing materials, the K-C Study found that different wetland communities and indicator species are correlated with different depths to water table. The Study derived graphs showing the likelihood of a given community or species occurring at a given depth to water table. From these graphs, one can predict the likelihood that a given change in the water table will cause a change in the persistence of an indicator species or a wetland community type.

Graphs 1 to 5, included as attachments, show how the Study predicts wetland species and communities will change in response to changes in depth to water table.

Because the predicted changes in wetland community type or loss of an indicator plant or wildlife occurrence may not take place suddenly at one specific of water table change, it is not possible simply to extract one, definitive amount of change or depth to water table as the threshold for each indicator. Instead, policy makers will have to choose a threshold at which the likelihood of causing a negative change is deemed acceptable vs. unacceptable.

Question B: *When should applicants have to show other sources (surface water or deeper aquifers) are not available before using the Kirkwood-Cohansey for new or increased withdrawals?*

The Kirkwood-Cohansey aquifer is unique in our region because it is a surficial, water table aquifer on which the surface and aquatic ecology of the outer coastal plain and estuary system relies. There are generally technologically possible alternatives to using the Kirkwood-Cohansey for new or increased allocations, particularly deeper, confined aquifers or surface waters. (We treat conservation measures and more efficient use of the resource in a separate set of questions below.)

Permitting agencies, therefore, might consider a policy that sets use of the Kirkwood-Cohansey as a "last resort" in all or in specified circumstances, even when the specific proposed withdrawal would meet the individual regulatory criterion.

We will consider the following policy options for when applicants would be required to show alternative sources are not available before considering new or increased Kirkwood-Cohansey withdrawals:

PO9 Always.

PO10 Never.

PO11 When the watershed is already stressed due to existing allocations, per the criteria governing new allocations.

PO12 When the application is for a disfavored or optional use.

To implement any of these options, it would be necessary to define when alternatives sources are considered to be available. Particularly: Should alternatives be required when technologically possible, or should there be some measure of cost included in the definition?

To implement PO11, it would be necessary to define disfavored or optional uses. For example, some would view irrigating a golf course or a corporate property as a disfavored or optional use that does not justify using Kirkwood-Cohansey water.

Question C: *Should permitting criteria be universal for all Kirkwood-Cohansey withdrawals, or should they vary by whether the withdrawal will affect designated conservation zones versus growth zones?*

The Pinelands National Reserve and Comprehensive Management Plan covers most of the extent of the Kirkwood-Cohansey aquifer, and the State Plan covers the rest. Both programs identify growth and conservation zones. DEP and the Pinelands Commission may consider applying different standards for environmental impact to wells that will affect streams and wetlands within growth zones and non-growth zones.

We will consider the following potential approaches to whether the regulatory criteria for permitting new or increased allocations should vary by planning areas:

PO13 Standards should be universal for all Kirkwood-Cohansey withdrawals.

PO14 Standards should be less stringent for impacts in Pinelands Regional Growth Areas and similar designated high-growth planning zones, and more protective in other Pinelands management areas and non-Pinelands areas designated for conservation or rural character.

PO15 Resource-specific – Standards should be tailored in cases where withdrawals will affect waters having unique ecological, historic, recreational or other special values.

Question D: *What role if any should water conservation measures play in meeting regulatory requirements for new or increased withdrawals?*

A number of water conservation measures are available which could bring quantifiable savings in water use, as discussed in the Water Conservation section of this briefing.

DEP and/or the Pinelands Commission could, therefore, require or allow applicants for new or increased allocations to implement water conservation measures as a condition of granting the allocation – either to off-set expected impacts in all cases, or as a means to meet the regulatory criteria when the proposed allocation by itself would otherwise exceed the permitted impacts.

The Pinelands CMP already requires that applicants seeking to develop water supply wells or expand water distribution systems must "address" water conservation measures, but this provision has not been enforced.

Requiring water conservation measures, even when a proposed allocation meets the regulatory criteria for its direct impacts, could serve to alleviate the cumulative impacts of existing and future withdrawals and provide greater room for future, sustainable uses.

It would also be possible to require conservation for certain uses deemed nonessential and not for others uses deemed essential; based on the sector having the greatest impact on the aquifer in a given watershed; or based on a desire to discourage certain disfavored uses by placing additional requirements on those uses.

Permitting the use of conservation to bring an otherwise non-compliant allocation into compliance could be justified if (a) the conservation measures reduce withdrawals affecting the same streams and wetlands as the new allocation, and (b) the measures are reliable and enforceable over the long-term future.

We will consider the following policy options for incorporating conservation measures into the permitting of new or increased allocations:

PO16 Quantifiable water conservation measures should be required, in the same sub-watershed, to offset expected impacts of withdrawals.

PO17 Quantifiable water conservation measures should be required to offset expect impacts but only for certain kinds of uses.

PO18 Applicants should be permitted to use quantifiable conservation measures to off-set withdrawals that otherwise exceed the regulatory limits.

Question E: *Should DEP and/or the Pinelands Commission create a new "fail safe" mechanism to suspend future allocations or reduce current allocations where actual impacts or trends turn out to be significantly greater than anticipated?*

The application of regulatory criteria to water allocation requests relies on the use of models to predict the impact of the proposed well given the natural hydrology and pre-existing withdrawals from the aquifer. But our understanding is imperfect. These models may turn out to be incorrect in some cases, and we may find that stream flows or water table levels are falling more dramatically or faster than assumed when allocations were approved. Should the state agencies build fail-safe mechanisms into their rules so they can suspend additional allocations or even reduce existing withdrawals when they see impacts that substantially exceed their predictions?

We will consider two options for answering this question:

PO19 Set a regulatory trigger that suspends new or increased allocations in a watershed when a trend of increasingly severe impacts of current withdrawals shows the modeling on which permits are based is inaccurate.

PO20 Set a regulatory trigger that reduces existing allocation limits within a watershed when a trend of increasingly severe impacts of current withdrawals shows the modeling on which permits are based is inaccurate.

II. Water Supply Planning

In addition to revising their regulatory criteria for the case-by-case permitting of Kirkwood-Cohansey withdrawals, DEP and the Pinelands Commission may undertake new proactive planning to ensure sustainable use of the region's aquifers while serving current and future demand.

Such planning would presumably be done in a manner consistent with DEP's State Water Supply Plan, which has been in process for several years and may be released soon. While we do not yet have the new State Water Supply Plan to help inform our discussion, we have enough information about its structure and approach to conclude that more detailed planning for the Kirkwood-Cohansey aquifer could be done in a number of ways consistent with this Plan when it is released.

Question F: *How should water allocation planning for the Kirkwood-Cohansey aquifer be structured?*

We will discuss some very basic approaches to structuring a plan so that it achieves the desired goals. What do we want the plan to tell purveyors, government agencies, and consumers so that it will be effective in guiding their actions?

PO21 Set targets for total withdrawals from the aquifer in each basin.

PO22 Set limits and options for total withdrawals from the aquifer in each basin.

PO23 Set limits and options for each purveyor's use of the aquifer.

Question G: *What role should water supply alternatives, such as aquifer or surface water storage, conjunctive use, infrastructure upgrades play in water supply planning?*

There are always alternative sources of water to using the Kirkwood-Cohansey, though the alternatives may have other impacts or costs that make them more or less desirable and feasible in any given situation. These sources are summarized in the Alternative Water Sources sections of these materials.

Assuming alternative sources would in some cases yield better outcomes for natural resource conservation, how should DEP and the Pinelands Commission incorporate the consideration of these sources into their water supply planning?

It is also significant that the Kirkwood-Cohansey aquifer is hydrologically connected with deeper, semi-confined and confined aquifers. This connection is especially important in the case of the Atlantic City 800-Foot Sands aquifer, which is recharged by water from the overlying Kirkwood-Cohansey aquifer. In 2009, there were 108 wells in the Atlantic City 800-Foot Sands drawing almost 25 million gpd from the aquifer.

We will consider the following policy options, which again are not mutually exclusive:

PO24 DEP and the Pinelands Commission should incorporate water supply alternatives in the planning process.

PO25 DEP and the Pinelands Commission should set explicit criteria for determining when each potential alternative source will be considered available, desirable and required for consideration by purveyors.

PO26 DEP and the Pinelands Commission should incorporate water supply alternatives into targets, limits and options for those basins where the aquifer is already stressed.

PO27 DEP and the Pinelands Commission should incorporate impacts to and withdrawals from connected aquifers, such as the Atlantic City 800-foot Sands, I planning for the Kirkwood-Cohansey aquifer.

Attachments:

Map 1 – Kirkwood-Cohansey Aquifer with Pinelands National Reserve boundary

Map 2 – Kirkwood-Cohansey Aquifer with Urban/Suburban Land Use and Preserved Lands

Map 3 – Kirkwood-Cohansey Aquifer with Public Supply Wells (2009)

Map 4 – Kirkwood-Cohansey Aquifer with Irrigation Wells (2009)

Chart 1 – Tuckahoe River Flows 1969-2012

Chart 2 – Tuckahoe River Flows 1969-2012 (Logarithmic Scale)

Chart 3 – Tuckahoe River Flows 1969-2012 Under 20 MGD

Chart 4 – Hypothetical Drought Hydrograph of Pine Barrens River with Regulatory Threshold Options

Graph 1 - Wetland Vegetation Response to Depth-to-Water Table

Graph 2 - Pond Vegetation Response to Reduction in Water Depth

Graph 3 - Swamp Pink Response to Water Level Reduction

Graph 4 - Pine Barrens Treefrog Metamorphs Response to Water Level Reduction

Graph 5 - Aquatic Invertebrate and Fish Response to Streamflow Reduction

References

Illustrations for Kirkwood-Cohansey Aquifer Forum Briefing Paper

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