APPENDIX G
ATTACHMENT G-2

WETLANDS RESTORATION SUCCESS

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PSE&G RENEWAL APPLICATION
SALEM GENERATING STATION
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I. INTRODUCTION

Public Service Electric and Gas Company's (PSE&G) wetland restoration program is the largest salt marsh restoration program of its kind in the country. More than 20,500 acres (approximately 30 square miles) of salt marsh and upland along the Delaware Estuary in both New Jersey and Delaware are being restored, enhanced, and/or preserved as part of the program. Through this program, PSE&G has restored substantial detrital production to the estuary and provided refuge, feeding, breeding, and nursery habitat for important estuarine fish and shellfish.

Salt marshes are among the most productive ecosystems on earth. The biomass produced by the marsh vegetation and algae is decomposed and passed along the food web to fish and invertebrates. "A maze of tidal creeks with plankton, fish, nutrients and fluctuating water levels crosses the marsh, forming conduits for energy and material exchange with the adjacent estuary" (Mitsch and Gosselink 1993). These exchanges are disrupted and estuarine productivity is impacted when wetlands are lost and degraded.

Restoration of degraded estuarine marshes has the greatest probability of success when the right lands are selected, the right design is implemented, and the right follow-up is pursued. PSE&G selected and acquired lands with conditions that favored successful restoration. These lands were formerly functioning salt marshes. Marsh plain elevations and groundwater and tide relations were appropriate for restoration; plant propagules (seeds, rhizomes, larvae, etc.) were present in the marshes or neighboring marshes; animals that would populate the marshes were present nearby; and sediments of appropriate organic and nutrient content for marsh restoration were present in the tidal waters. The restoration design was based on ecological engineering, which is an integrated approach to environmental management that assures the restoration follows the most natural path, the path most likely to be stable into the future. The restoration success is being assured through a program of Adaptive Management that provides a framework for identifying and implementing actions necessary to keep the restoration on track.

PSE&G's program is successfully restoring natural and productive structure and function to the degraded wetlands. Normal tidal inundation is largely present at all sites, and natural geomorphology is developing rapidly. The sites have been colonized by desirable vegetation, and this vegetation is expanding across the restored areas. Productivity of the returning desirable vegetation and algal communities is comparable to that measured in nearby healthy reference marshes. Clearly, all of the restoration sites are on a trajectory for success. This is borne out by the fact that the sites are being used by a diverse and abundant fish population for feeding, reproduction, and nursery areas, and by the transition to a bird and wildlife community more typical of natural wetlands. While the restoration process is in a very early phase, the contribution of the restored areas to the productivity of the Delaware Estuary will be a permanent feature of the region.

This Attachment and its Exhibits demonstrate that PSE&G's wetland restoration and preservation program achieved this success in a scientifically sound manner. Section II of the Attachment provides background information regarding wetland function and restoration in general, and the basis for PSE&G's program in particular. Section III presents detailed information regarding the implementation and status of PSE&G's restoration and preservation activities. Section IV discusses the Adaptive Management Program that PSE&G is using to assure restoration success. Finally, Section V provides a brief statement of overall conclusions.

Exhibits to this Attachment address specific technical issues in detail. These Exhibits are:

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II. BACKGROUND

Tidal wetlands are uniquely important and valuable ecosystems. The first compilation and development of ecological principles (Odum 1953) emphasized the value of tidal wetlands for supporting estuarine fisheries and food webs:

> ...silversides, killifish, and flounders...and other species...move back and forth with the tides, feeding on benthos of the intertidal zone when it is covered with water. Likewise, shorebirds move back and forth on the intertidal zone hunting for food when it is uncovered. It is remarkable that anything is left after these alternate attacks from land and sea!

Yet, things are "left" to support the continual trophic needs of the estuary because healthy tidal marshes produce enormous quantities of food and possess the habitat, structure, and functional linkages to make that food readily available on an ongoing basis to consumer organisms like invertebrates, fish, and birds using the estuary and nearby coastal oceans (Teal and Teal 1969).

As discussed in this Attachment, human damage to and elimination of tidal wetlands are ecological impacts of great significance for the biodiversity and sustainability of estuarine and coastal ecosystems. But such impacts are more than quantitative changes of scientific interest. They are spiritually important and impoverish not just the ecological support systems on which humans depend for food and shelter, but the ethical terms on which we meet the rest of the world. Ecosystem losses alter the physical and biological systems to which organisms (including humans) are adapted and within which they must prosper. An early exposition of ecological ethics (Kozlovsky 1974) summarized some principles of adaptation and environmental impact:

> *It is essential for the full development of any organism that it encounter an environment to which it is adapted*, for the organism is a bundle of adaptations; in an inappropriate environment these adaptations are frustrated and the organism becomes distorted or

> diseased. *And it is essential that a species not destroy the environment that it needs.* (Italics from the original.)

Organisms are maladapted when the ecosystems to which they have evolved are drastically altered. The alternative to adaptation is extinction (Kozlovsky 1974). In practice, loss and alteration of wetlands change adaptive relationships by altering the ecology of the entire estuary and coastal system. When altered, populations of fish, shellfish, and birds, adapted to natural coastal landscapes, do not receive the full measure of trophic and habitat support required for ecosystem health. Restoring functional, fully linked tidal marshes returns the natural system to which organisms are adapted and from which the productivity of these areas is integrated into the coastal ecology. Kozlovsky (1974) emphasizes the critical importance of asking, in reference to habitat loss and alteration, "whether or not we can stop it, whether we can reverse it…."

PSE&G's wetland restoration program answers this question. We *can* stop the loss of coastal wetlands; we *can* reverse the effects of decades of human impact. By successfully restoring wetlands at large scale, PSE&G has restored a good measure of the natural, linked ecology to which organisms are adapted and on which the entire coastal system, from the fall line at Trenton to the continental shelf off Atlantic City and Rehoboth, depends.

II.A. Wetlands Degradation and Loss, Restoration, and Sustainability

Coastal wetlands are enormously valuable, for the productivity and habitat value they provide in themselves and for their role in linking aquatic and terrestrial ecosystems (Montague and Odum 1997). The U.S. Environmental Protection Agency (USEPA 1998) concurs, stating that coastal wetlands:

> …are extraordinarily productive habitats that offer protective shelter and abundant food to juvenile fish, shellfish, migrating waterfowl, and thousands of other species….Coastal wetlands also buffer the coastline from severe storms and intercept nutrients and sediments….Ecologists estimate that more than half of the [Mid-Atlantic, including Delaware Bay,] region's wetlands have been lost because of human activities dating from pre-colonial times.

USEPA also recognizes that the value of the system depends on the multihabitat nature of the coastal complex (USEPA 1998):

> Presently, about two thirds of the coastal wetlands are salt marshes colonized by salt-tolerant grasses and bushes. Much of the balance [is] tidal mud flats, areas that are exposed at low tide and are densely packed with shellfish, invertebrates, crabs and other organisms. The remainder [is] freshwater marshes, forests, and shrublands.

In the region as a whole, USEPA estimates that loss of tidal wetlands has recently slowed; however, historical losses were severe. From 1953 to 1975, New Jersey alone lost 25 percent of its tidal wetlands, with the vast majority in counties bordering the Delaware Estuary (Tiner 1985). This is in addition to losses through 1953, when much of the agricultural and industrial development and urbanization of the coastline occurred. The practice of diking tidal marshes for hay production began in the 1600s and continued at an accelerating pace through the 1700s and 1800s in Salem, Cumberland, and Gloucester counties. Indeed, diked wetlands occupied much of the Delaware coastline up-estuary from Cumberland County by the late 1700s (Wacker and Clemens 1995). These diked wetlands are isolated from the estuary, contributing little productivity and few other benefits to the ecosystem.

Much of the remaining coastal wetlands has been severely impacted by human activities and other disturbances, and "the challenge now is to ensure that the wetlands are healthy despite severe anthropogenic stresses" (USEPA 1998).

Among the most important stresses impacting coastal wetlands of the Delaware Estuary is the aggressive and highly persistent colonization by stands of common reed (*Phragmites australis*). Common reed was historically a relatively minor component of healthy, diverse coastal wetlands in North America (Niering and Warren 1977). Earlier in this century, *Phragmites* stands expanded, outcompeting other wetland species and monopolizing large areas (Hauber et al. 1991; Besitka 1996).

The spread of common reed has been particularly aggressive in the Mid-Atlantic region (Exhibit G-2-6). In the Delaware Estuary, the sudden and dramatic invasion of formerly healthy marshes can be seen in historical aerial photographs. Exhibit G-2-17 presents a comprehensive analysis of *Phragmites* spread at the PSE&G *Phragmites*-dominated restoration sites.

In dense stands over large areas, *Phragmites* interferes with the healthy functioning of coastal wetlands by blocking, slowing, and reducing the linkage between marsh primary production and estuarine food webs (Weinstein and Balletto in press; Jones and Lehman 1987; Schleyer and Roberts 1987; Exhibit G-2-6). The marsh surface is elevated so it is flooded less of the time, and the smaller creeks are blocked and eventually lost. When this happens, the habitat value of the marsh is reduced. Fish, shellfish, and other aquatic invertebrates are unable to access the marsh surface for feeding. When fish and shellfish are unable to reach the food resources of the marsh and the habitat is otherwise degraded, the value of the marsh to the estuarine ecosystem is lost.

The health of the entire estuarine and coastal ecosystem complex is related to the health of the wetlands that provide critical habitat and trophic support. Therefore, restoration of degraded wetlands is an important and timely objective for ecological science. To successfully restore a formerly functioning wetland, it is critical that conditions favoring successful restoration exist. A successful restoration can be accomplished when the marsh plain elevations and the groundwater and tidal relations are appropriate: the propagules (seeds, rhizomes, larvae, etc.) are present in the marshes or neighboring marshes; animals that would populate the marshes are present nearby; and sediments of appropriate organic and nutrient content for marsh restoration are present in the tidal waters. Basic scientific principles for re-establishing the many values lost by degradation of the wetlands are best based on ecological engineering, a powerful and valuable tool for managing ecosystems (Mitsch and Jorgensen 1989). Ecological engineering is a restoration approach in which human engineering is used to initiate and encourage natural processes, which are then allowed to complete the restoration.

Using ecological engineering, human engineering is implemented at the level appropriate to initiate natural processes, and is applied based on environmental conditions. Designs are adjusted based on oversight by experts in wetland science to account for environmental conditions during construction. Once wetlands are restored, natural relationships take over and contribute to ongoing and long-term maintenance: "Once restored, salt marshes should be self-perpetuating and require minimal management" (Burdick et al. 1997). This is not to suggest that ongoing intervention, oversight, or adjustment may not be necessary, particularly for control of invasive *Phragmites*. But taking maximal advantage of natural engineering minimizes the need for human engineering and allows natural ecosystem development. This is enhanced by applying adaptive management principles to long-term maintenance and management decisions. Thus, proper application of engineering and ecological principles together contributes to long-term sustainability in restored systems.

Ecological sustainability is the goal of environmental management, particularly the management of human impacts:

> It is clear that the rate of exploitation by humans of many natural coastal ecosystems for food, fuel, and other items is unsustainable. Sustainable exploitation of renewable resources depends on managing the resources to ensure that the rate of extraction does not exceed the rate of replacement...(Alongi 1998).

Successful management for sustainability requires the application of multidisciplinary expertise and integrated understanding of ecological relationships. Indeed, the concept of Integrated Coastal and Ocean Management (ICM) is rapidly becoming the state-of-the-art for regulating and controlling global coastal ecosystems (Cicin-Sain and Knecht 1998). ICM is:

> ...a conscious management process that acknowledges the interrelationships among most coastal and ocean uses and the environments they potentially affect. Hence, in a geographical sense, ICM typically embraces upland watersheds, the shoreline and its unique landforms (beaches, dunes, wetlands), nearshore coastal and estuarine waters, and the ocean beyond....ICM is a process by which rational decisions are made concerning the conservation and sustainable use of coastal and ocean resources and space. The process is designed to overcome the fragmentation inherent in single-sector management approaches....ICM is grounded in the concept that the management of coastal and ocean resources and space should be as fully integrated as are the interconnected ecosystems making up the coastal and ocean realms...if a degraded coastal habitat affects the attainment of fisheries management goals, management of that habitat should be within the ambit of an integrated coastal management process.

The wetlands restoration and enhancement conditions to the Permit recognize the integrated nature of the coastal system and prescribe an effective and scientifically sound approach that matches the fundamental integration of the ecosystem (of fish populations, tidal wetlands, and estuarine and coastal waters) as contemplated by ICM.

By successfully implementing the Special Conditions of the Permit, the New Jersey Department of Environmental Protection (NJDEP) and PSE&G have re-established powerful links in the chain of coastal ecosystems that together provide the enormously valuable environmental services to the estuary and ocean.

II.B. Technical Basis for the NJPDES Permit Wetland Requirements

The wetlands restoration Special Conditions of the NJPDES Permit were developed based on scientific findings regarding the nature of estuarine ecosystem integration and site-specific conditions in the Delaware Estuary. The foundations for the wetlands restoration Permit requirements are described below:

- Healthy tidal wetlands are critically important components of the integrated coastal ecosystem, and provide habitat and food web support to fish and shellfish populations.
- Diking and *Phragmites* invasion severely degrade Delaware Estuary wetlands.
- Degraded wetlands in the Delaware Estuary could be successfully restored.
- Wetlands restoration would contribute to increased fish production and provide other benefits to fish, shellfish, and wildlife in the Delaware Estuary.
- Restored wetlands would provide long term benefits to the Delaware Estuary, far beyond the life of the Salem Generating Station.

Since the Permit was issued, additional restoration programs have been implemented, including those reported in the published literature and PSE&G's own program, and provide further support the technical basis for the Permit.

II.B.1. Healthy Tidal Wetlands are Critical Ecosystems and Provide Habitat and Food Web Support to Fish and Shellfish

Estuarine wetlands provide habitat for many kinds of fish and shellfish, and make important contributions to the food webs of the coastal ecosystem. A "food web" is the pattern of relationships among organisms that eat and are eaten in the ecosystem. Green plants, such as marsh algae and grasses, trap energy from sunlight and produce plant tissues (biomass). This biomass in turn supports the fish, shellfish, and other organisms of the coastal ecosystem.

Food webs in healthy tidal marshes are of two fundamental types: grazing (on living plant material) and detritus-based (via decomposition) (Vernberg 1993). Grazing pathways involve direct consumption (herbivory) of macrophytes, like marsh grasses, as well as microscopic and macroscopic algae. Grazing on marsh grasses, such as *Spartina* and *Scirpus*, is responsible for only about nine percent of net primary production (Pfeiffer and Wiegert 1981). However, grazing by invertebrates and fish on bottom dwelling (epibenthic) and grass-stem dwelling (epiphytic) microscopic and macroscopic algae is a quantitatively important process in tidal marshes (Vernberg 1993).

Most of the energy from primary production in healthy coastal wetlands is passed through the food web via the detritus pathway. "Detritus" is the technical term for plant material that is decomposing and inhabited by a great variety of fungi, bacteria, yeasts, protozoans, nematodes, and other microscopic organisms that break down the plant material. It is largely the bodies of the decomposer organisms that serve as food from detritus.

In tidal marshes, standing dead shoots and leaves of *Spartina* and other desirable, naturally occurring marsh vegetation are partially decomposed in place, and this energy is transferred to the marsh food web (Newell and Barlocher 1993; Currin et al. 1995). The remainder falls to the marsh surface and is decomposed in and on the sediment by microbes and invertebrates (Vernberg 1993). Energy from the plants is passed up the food web when the detritus (including the decomposer organisms) is eaten by other animals such as worms, snails, crabs, and fish that are in turn eaten by larger crabs and fish.

Decomposition of below-ground components of wetland grasses is of major importance in marsh energy flow. Decomposition within the sediment occurs at rates comparable to that of aerial parts of the plants (White and Howes 1994), and below-ground detritus can be a large component of the overall marsh food web (Howes et al. 1985). Below-ground biomass is passed up the food web via decomposition and a substantial portion is available to the aquatic web (Howarth and Teal 1980).

Healthy tidal wetlands that are linked to estuarine and coastal waters provide critical ecosystem support through direct contribution to food webs and by serving as highly favorable habitat for aquatic organisms. In particular:

- Marsh creeks are used for feeding, breeding, and shelter by a variety of fish and invertebrates, and marshes are important habitat for both estuarine resident and continental shelf species (Talbot and Able 1984; Rountree and Able 1992; Shenker and Dean 1979; Weinstein 1979; Rozas and Hackney 1984).

- Consumer fish in marshes feed on abundant bottom-dwelling invertebrates (Boesch and Turner 1984; Smith et al. 1984).

- The movement of fish in and out of wetland areas is an important energy transfer linkage between marshes and estuarine and coastal waters (Weinstein and Walters 1981; Conover and Ross 1982; Currin et al. 1984; Cadigan and Fell 1985; van Montfrans et al. 1991).

- Large carnivorous fish (including such commercially and recreationally valuable species as weakfish *(Cynoscion regalis)*, summer flounder (*Paralichthys dentatus)*, striped bass (*Morone saltatrix)*, and bluefish (*Pomatomus saltatri*x) use the estuary on a seasonal basis and derive substantial food resources from forage fish and shellfish associated with marshes (Pennock 1988).

These findings have been confirmed, extended, and supported by recent studies and reviews. Large, carnivorous estuarine fish species have been documented to use shallow nearshore waters to a greater degree than was previously realized (Rountree and Able 1997; Exhibits G-3-1, G-3-3, and G-3-5). Growth and survival of many species is promoted by tidal wetland habitats (Kneib 1997), and marshes are important contributors to growth of early life history stages (Ayvazian et al. 1992; Baltz et al. 1993; Kneib 1997, Exhibits G-3-4, G-3-6, G-3-7 and G-3-9). In addition to food, marshes provide fish and shellfish with other important habitat support (Attachment G-3 and Exhibits G-3-4, G-3-5, G-3-9 and G-3-10). Water on the marsh surface may shelter fish from cold winter temperatures (Smith and Able 1994) and provide optimal temperatures for growth during the active season (Brett et al. 1969; Pietrafesa et al. 1986). Marshes may shelter some fish from predation (Nixon and Oviatt 1973; Joseph 1973), but also serve as a focus for feeding by trophic generalists (Moyle and Cech 1996). Tidal wetlands provide important spawning habitat, for both marsh resident species and other estuarine fishes (Moyle and Cech 1996, Exhibits G-3-6 and G-3-7).

While much remains to be learned about the mechanisms by which tidal wetlands contribute to estuarine and coastal fish populations, the overall role of marshes in supporting estuarine and coastal fish and fisheries is now well known to estuarine ecologists.

II.B.2. Diking and Phragmites Invasion Severely Degrade Delaware Estuary Wetlands

In degraded marshes, whether they are diked or invaded by *Phragmites*, trophic exchange pathways are interrupted and much less food web support is provided from the wetland to the estuary.

Dikes interfere with tidal exchange, drastically change the wetland ecosystem in the diked area, and reduce or eliminate the contribution of the wetland to estuarine and coastal marine food webs (Niering and Warren 1980; Roman et al. 1984; Roman et al. 1995). Where dike systems are complete and no regular tidal exchange occurs, diked marshes are completely eliminated as contributors to healthy estuaries. Where dike systems are breached by tide gates or other partial barriers, some linkage with the estuary is maintained, but is significantly reduced. Once marshes are diked, they are no longer a component of an integrated, healthy, functional coastal ecosystem (Cicin-Sain and Knecht 1998). Estuarine fish and shellfish lose the food and habitat value they would otherwise obtain from the marshes. The loss of habitat and trophic support from diked intertidal marshes is reversible, and ecosystem integration can be achieved through restoration (Burdick et al. 1997).

Invasion by *Phragmites* also disrupts the linked and integrated nature of the coastal ecosystem, making it impossible for fish and shellfish to obtain full advantage from the habitat and food of the marsh. Dense, large *Phragmites* stands elevate the marsh plain by accumulation of undecomposed litter and sediment deposition, whereas *Spartina* and other grasses leave the marsh surface in equilibrium with the tides. The elevated surface associated with *Phragmites* stands and elimination of small tidal drainage channels (microtopographic relief) (Windham 1995) reduces or eliminates access to the marsh for much of the aquatic food web, including forage fish and invertebrates that serve as trophic support for larger predatory species, some of which are commercially and recreationally important species (Weinstein and Balletto in press). In addition, dense large stands of *Phragmites*:

- Reduce the amount of food available through the detritus pathway due to slow decomposition of stem biomass relative to wetland species replaced (Buck 1995; Windham 1995), as demonstrated by a thick layer of undecomposed stems on the marsh surface in *Phragmites* stands;

- Drastically reduce the diversity of the ecosystem by out-competing important marsh plants as *Spartina*, *Distichlis*, *Scirpus*, *Typha*, and other desirable, naturally occurring marsh vegetation (Lapin and Randall 1993; Haslam 1971; van der Valk 1986; Thompson and Shay 1989; Marks et al. 1994);

- Substantially lower the value of a wetland site as habitat for birds and wildlife (Ricciuti 1983; Lapin and Randall 1993; Roman et al. 1984; Jones and Lehman 1987; Tiner 1985; Clark 1994); and

- Interfere with nutrient cycling processes, binding limiting nutrients in forms unavailable to other plants (Ahearn et al. 1996). Nutrients are the fertilizers necessary for the growth of desirable, naturally occurring marsh vegetation, and *Phragmites* reduces the quantity of nutrients available to other species.

The physiology, ecology, and relationships of *Phragmites* are presented in detail in Exhibit G-2-6. As is true for diked wetlands, the ecosystem degradation associated with *Phragmites* invasion is reversible (Jones and Lehman 1987).

II.B.3. Degraded Wetlands of the Delaware Estuary Can be Successfully Restored

Degraded wetlands can be successfully restored where conditions favoring restoration exist, an appropriate design properly addressing ecological considerations is implemented, and the program is monitored and managed to ensure the restoration becomes self-sustaining.

Where these conditions exist and approaches are used, wetlands restoration projects have the greatest probability of success. Depending on the circumstances under which a particular project is undertaken, it is often possible that some but not all of these conditions will exist or be possible to use. However, the application of these concepts helps assure success, even when the entire suite of principles cannot be applied.

The Permit application and supplemental documentation (Appendix Q-1 and the Permit Renewal Application Supplement) summarized the literature on wetlands restoration and described marsh restoration projects that offered methodological precedents and demonstrated the effectiveness of restoration techniques for the PSE&G restoration program. These restorations were all similar in one or more ways to PSE&G's restoration program, and all applied one or more of the restoration principles described above. Many involved dike breaching as a primary restoration tool; some included direct *Phragmites* control. These projects and their present status are described below:

- Pine Creek Marsh, Fairfield, CT. Tidal flow was restored in 1980 at this marsh that had been diked and heavily degraded by *Phragmites*. Today this marsh has a low level of *Phragmites* in the vegetation community, and is dominated by *Spartina* species, *Distichlis*, and other desirable, naturally occurring marsh vegetation (Niering 1997).

- Moores Beach West and Wheeler's Farm, Delaware Estuary, NJ. These marshes, diked in the 1800s, were restored by dike breaching in the 1980s. Today they are healthy, linked tidal wetlands (Exhibit G-2-2).

- Mosquito Control Project, Cape May County, NJ. These mosquito control restoration projects continue to exhibit the characteristics of healthy marshes, including the presence of diverse biota on site and linkage to the estuary, with drastically reduced dominance by *Phragmites*. A recent example is the Green Creek Marsh in Cape May National Wildlife Refuge. The dike of this former salt hay farm site was breached in 1996/7, and there has subsequently been a reduction in *Phragmites* dominance by more than 90 percent (J. Hansen, personal communication)

- Saw Mill Wildlife Management Area, Hackensack Meadowlands, NJ. This diked area was breached by a hurricane in the 1950s. Today it supports a functional, diverse plant community that includes *Spartina*, *Eleocharis*, upland islands, and channels, where formerly *Phragmites* was nearly monospecific (M. Laska, personal communication).

- Hartz Mountain, Hackensack Meadowlands, NJ. Diked in the first half of this century, the site has been restored using a combination of methods. Today the Eastern Brackish Marsh area is dominated by mud flats favored by shorebirds and wading birds. The Western Brackish Marsh area supports a diverse plant community that includes *Spartina* cordgrass and other favorable species (M. Laska, personal communication).

- Lincoln County Tidelands, Salmon River, Oregon. Diked in the 1960s, restoration was initiated in 1978. The site now supports a more natural and diverse plant community and a tidally linked wetland ecosystem (R. Frenkel, personal communication).

Since the Permit was issued, a number of additional wetland restoration projects have been implemented, evaluated, and published. These more recent projects all incorporated one or more of the wetland restoration principles in their design and implementation. These restoration projects all have relevance for PSE&G's program, because all are diked marsh restorations with renewed estuarine linkage:

- Drakes Island Marsh (Maine) and Mill Brook Marsh (New Hampshire). These sites are formerly diked marshes with tidal flow recently restored. At Mill Brook, where full tidal exchange was effectively restored, healthy marsh structure and processes returned rapidly. At Drake's Island, tidal flow was not fully restored, and the vegetation recovery has lagged (Burdick et al. 1997).

- Tidal Wetlands, Vero Beach, FL. An impounded wetland was reconnected to the estuary. The system has matured and the restoration is considered a success, with tidal exchange supporting use of the restored area by fish, crustaceans, reptiles, and mammals, including the endangered manatee (Beeman 1992 and 1999, personal communication).

- Barn Island, Stonington, CT. Tidal flow was restored to a series of impoundments where salt marsh vegetation had been replaced by *Phragmites* and non-salt tolerant plants. Following restoration of full tidal exchange, establishment of desirable salt marsh grasses, and recolonization and use of the area by fish, birds, and invertebrates typical of healthy tidal marshes was rapid (Rozsa 1997; Brawley et al. 1998).

- Long Island Sound Marshes, Southern Connecticut. Restoration of tidal exchange to flow-restricted marshes resulted in a pattern of vegetation dieback (as salinity levels increased and accreted marsh plain re-established equilibrium with tide levels) and ongoing recovery of typical salt marsh mix of plants, tidal flats and open water (Rozsa 1997).

- Hammock River Marshes, Clinton, CT. Drained and dried marshes were restored to tidal flow by water management techniques, resulting in rapid and cost-effective recovery of a typical mix of salt marsh vegetation and mud flats, including a healthy and stable upland edge of appropriately diverse shrubs and grasses (Rozsa 1997).

In summary, it is clear from the high level of activity in the wetlands restoration field and the increasing body of knowledge regarding techniques and monitoring data that wetlands restoration is a valuable and effective tool for coastal environmental management. The "lesson learned" from previous restoration efforts is that wetlands in the Delaware Estuary can be successfully restored. The likelihood of success will be enhanced by applying, as PSE&G did, basic restoration principles: selecting lands with conditions favoring restoration; employing ecological engineering principles in design and implementation; and using adaptive management to ensure ongoing restoration success.

II.B.4. Wetland Restoration Contributes to Increased Fish Production and Provides Other Benefits to Fish, Shellfish, and Wildlife in the Delaware Estuary

Evaluation of the success of this effort is necessarily incomplete because the restoration itself is in early stages. However, even at this early stage of the restoration program, it is clear that the restoration is on a trajectory for success.

As described in Exhibit G-2-3, normal tidal inundation has largely been restored and natural geomorphology is developing rapidly. As described in Exhibit G-2-4, the coverage of *Spartina spp.* and other desirable, naturally occurring marsh vegetation is increasing, while the coverage of undesirable *Phragmites* is decreasing. Exhibit G-2-4 also demonstrates that the productivity of desirable, re-established marsh vegetation of the restored marshes already equals that of healthy reference marshes. As detailed in Attachment G-3 and summarized in Section III, the fish and shellfish communities of the Delaware Estuary have responded to the restoration by using the marshes for feeding and breeding. Finally, the restoration results in diverse habitat for abundant wildlife (Exhibits G-2-11, G-2-13) and provides numerous opportunities for recreation and environmental education (Exhibit G-2-14). When the restoration is complete on each site, the large-scale, integrated structure of the restoration will assure a permanent contribution to the Delaware Estuary in terms of productivity and habitat for fish, shellfish, and wildlife, and human access.

II.B.5. Restored Wetlands Would Provide Long-Term Benefits to the Delaware Estuary, Far Beyond the Life of the Salem Generating Station

The Station has a finite life. When the Station ceases operating, any impacts of the facility on the estuary will cease. Because the restored wetlands will continue to develop naturally, they will continue to provide benefits well beyond the life of the station.

Moreover, these wetlands contribute to an area of significant ecological value, as recognized by "The Convention on Wetlands of International Importance especially as Waterfowl Habitat" (commonly referred to as the Ramsar Convention). The Ramsar Convention addresses all aspects of wetlands conservation. The first obligation of the Ramsar Convention is to designate wetlands for inclusion in the "List of Wetlands of International Importance" (the Ramsar List). Selection for the Ramsar List is based on significance in terms of ecology, botany, zoology, limnology, or hydrology.

Seventeen wetland sites in the United States have been designated as Ramsar Convention Wetlands of International Importance. The Delaware Estuary and all wetlands lying therein comprise one of the seventeen sites which meets the critical and stringent Ramsar Convention guidelines and is designated as an internationally important wetland. All of the PSE&G wetland restoration sites are included within the Ramsar Convention Delaware Estuary wetland site (J. Laubengeyer, personal communication) and will contribute to the health of this important ecosystem long beyond the life of the Station.

The marshes of the Delaware bayshore are also identified as a "Last Great Place" by The Nature Conservancy's Last Great Places Alliance for People and Nature campaign. The objective of this $315 million campaign is the protection, through partnerships, community outreach, and land preservation, of the best remaining examples of ecosystem. By designating the marshes of the Delaware bayshore, a Last Great Place, The Nature Conservancy also has recognized the value of the ecosystem to which the PSE&G wetland restoration sites will contribute for the long term.

II.C. Restoration Approach

PSE&G's approach to restoration is intended to re-integrate degraded wetlands into the estuarine and coastal ecosystem. To meet this overall objective, the program incorporates two critical components: ecological engineering and adaptive management.

II.C.1. Ecological Engineering

Ecological engineering is an integrated approach to environmental management pioneered by W.J. Mitsch and S.E. Jorgensen in the late 1980s (Mitsch and Jorgensen 1989). Mitsch and Jorgensen developed the concept of ecological engineering as a strategic tool to help assure sustainable interactions between humans and the environment. For complex environmental management actions such as PSE&G's wetland restoration program, ecological engineering is the most effective and appropriate approach because it recognizes the importance of using human engineering to initiate and encourage natural processes which are then allowed to complete the restoration. Thus, ecological engineering assures that the ecosystem follows the most natural path, the path most likely to be stable into the future.

Ecological engineering is defined (Mitsch and Jorgensen 1989) as "...the design of human society with its natural environment for the benefit of both." The principles on which an effective ecological engineering program for wetland restoration is based are: 1) understanding wetland function; 2) giving the system sufficient restoration time; and 3) allowing for the self-designing capacity of the natural system (Mitsch and Wilson 1996). PSE&G's restoration program was founded on and maintains these principles.

Ecological engineering (Mitsch 1995) has been an integral component of PSE&G's restoration program from the initial planning phase. Wetland characteristics in the Delaware Estuary were investigated thoroughly before any restoration activities were undertaken. In selecting degraded wetlands for restoration, PSE&G considered the relationship between tide levels and vegetation, including local effects of diking and *Phragmites* invasion.

PSE&G prepared site-specific designs following detailed investigation of geomorphological, hydrological, and biological conditions at each site. Taken together, the understanding of wetland function developed on both estuary-wide and site-specific bases allowed PSE&G to optimize engineering parameters and maximize the opportunity for restoration success. Management Plans were scoped to incorporate the appropriate level of engineering necessary to allow natural engineering to take over the restoration process. For example, engineered creeks were designed for the low order tributaries, leaving the marsh to develop smaller creeks and microtopographic relief as appropriate to its own internal drainage pattern. In addition, seeds coming in with the tides formed the basis for revegetation of the sites. During the implementation of the designs, wetland scientists guided the construction to be sure that the restoration properly addressed environmental conditions evident at the time of construction to encourage the natural processes.

Individual site restoration Management Plans incorporated sufficient time for success, as determined by analysis of data on earlier restorations. Lag periods and vegetation recovery times were considered, and final restoration success criteria were developed after accounting for temporal processes (such as modes of plant reproduction and fauna colonization) that would affect the restoration period. It was anticipated that recovery would occur over a period of years following the completion of engineering activities on each site. The Adaptive Management program (below) was developed to monitor, guide, and respond to the temporal process of restoration by providing a means for implementing interim actions to help assure that final restoration goals are met.

II.C.2. Adaptive Management

While ecological engineering provides the principles on which the restoration program is based, adaptive management provides the tools to evaluate the projects to ensure the project is kept "on track." Adaptive management is a framework for identifying and meeting environmental management goals by an iterative process of monitoring and engineering response (Holling 1978). The ultimate objective of adaptive management is sustainable management of ecosystems in the context of human development (Thom 1996).

Because ecosystems are highly complex and ecological processes are very site-specific, it is only by obtaining and applying site-specific data that effective management can be realized (Haney and Power 1996; Walters and Holling 1990). This is particularly true for tidal wetlands, in which complexity is a function of, among other things, latitude, distance from the sea, local relative sea level rise, atmospheric and gravitational tidal effects, freshwater input, topography, substrate types, ecological history, and disturbance (Adam 1990; Kemp et al. 1992). Given the level of complexity in the ecology of tidal wetlands and the inability to completely understand the details of the functioning of these systems, adaptive management is the appropriate framework under which a successful large-scale environmental restoration can be conducted (Thom 1996).

The technical literature identifies two specific environmental restoration objectives that are addressed most effectively by adaptive management: ecological linkage repair and restoration (Heathcote 1998; Williams et al. 1997) and invasive species control (Barrett and Barrett 1997).

The first objective is to restore linkages between landscape components, including wetlands, uplands, and waterways. Meeting this objective provides the foundation for incremental increases in fish production for restored marshes. The second objective is to control weedy invaders, such as *Phragmites*.

PSE&G's adaptive management process was developed following a thorough review and consideration of other successful programs. In general, PSE&G's adaptive management approach is:

- Conventional and tested in concept, using "mainstream" techniques in accepted applications. As presented by Lee (1993), adaptive management for environmental restoration is based on objectives identified through stakeholder participation and monitoring of scientifically appropriate parameters, and active response to findings and reduced uncertainty resulting from data gathering efforts. These processes have been integral to PSE&G's wetland restoration program from its inception and as it is implemented on specific restoration sites.

- Technically rigorous and based on thorough scientific peer review. The stakeholders and independent scientists of NJDEP and MPAC provide ongoing advice and direction to the restoration program. Their input will continue as adaptive management is implemented on each restoration site. Components of PSE&G's adaptive management approach have been published in the scientific literature (Weinstein et al. 1997; Teal and Weinstein 1999) and continue to be submitted for scientific review (e.g., a session at the upcoming 1999 annual meeting of the Society of Wetland Scientists will be devoted to PSE&G's wetland restoration program).

- Comprehensive and effective. A broad suite of monitoring and management tools are considered. These range from basic field techniques with decades of testing (such as vegetation plot analyses) to techniques at the "cutting edge" of modern science (including high-resolution remote sensing and geographic information systems analysis).

- Systematic and objective. Central to the adaptive management process is establishing *a priori* criteria and thresholds to guide decisions and active response (Weinstein et al. 1997; Haney and Power 1996). This is particularly important in wetland restoration programs, where definitions of success and appropriate measurement techniques must be established to define whether objectives are met (Pacific Estuarine Research Laboratory 1990). PSE&G's Adaptive Management Program is based on expected recovery trajectories

(Weinstein et al. 1997) that provide an objective and systematic foundation for evaluating the program.

- Appropriately site specific. PSE&G's adaptive management program was developed based on specific recovery expectations for sites in the Delaware Estuary. The restoration incorporates two distinct categories of wetlands: diked salt hay *(Spartina patens)* farms and *Phragmites* degraded areas. Restoration times are expected to vary between these categories, and the adaptive management process explicitly incorporates recovery lag times appropriate to the specific site conditions.

In adaptive management, expectations for how a restored area will recover its structure and function (recovery trajectories) are derived from an understanding of basic ecology and site specific conditions. If expectations are met, actions are not needed; if expectations are not met, information is gathered and the restoration is corrected, if necessary, by active management response (National Research Council 1992). To implement this process for the PSE&G wetland restoration program, a rigorous and objective framework was developed for establishing expectations, comparing monitoring data, and determining causal effects.

There are two components of the PSE&G Adaptive Management Program: Restoration Management (RM) and Management Plan Required Adaptive Management (MPAM). These components are designed to work together to assure that the restoration projects meet their site-specific objectives in a timely and effective fashion.

II.C.2.a. Restoration Management

To help assure success of the restorations and avoid triggering Management Plan-required adaptive management responses, PSE&G developed and implemented an ongoing program of restoration management using an adaptive management framework and approach. This is a program of ongoing observation and response conducted by an adaptive management team consisting of wetlands and ecological engineering experts along with restoration managers who frequently visit and observe the sites. The team makes regular visits to all the restoration sites to evaluate progress and observe conditions. Problems such as premature dike breaches, sediment erosion, poor drainage, sedimentation, or other conditions that might ultimately interfere with restoration success are addressed on an ongoing basis. In this way, the restoration process is kept on track continually and the likelihood of timely success is maximized.

II.C.2.b. Management Plan Required Adaptive Management

Management Plans for each restoration project identified restoration goals in measurable terms. In particular, specifications were provided for aerial coverage reduction of *Phragmites*, coverage gains of desirable, naturally occurring marsh vegetation, drainage, flooding, and erosion. Objectives were set based on conditions in nearby natural and naturally restored marshes (Weinstein et al. 1997). These conditions were evaluated to determine how a successfully restored ecosystem would be structured at a particular point in time. This defined the expected restoration trajectories for the restoration and the "bounds of expectation" that defined ultimate restoration success. Failure to meet expectations in a particular period will trigger an adaptive management response, beginning with additional information gathering and ending with additional restoration engineering if warranted based on findings.

III. PSE&G'S WETLANDS RESTORATION PROGRAM

III.A. Overview of PSE&G's Wetland Restoration and Preservation Program

PSE&G's 1994 New Jersey Pollutant Discharge Elimination System (NJPDES) Permit (the Permit) for the Salem Station included a number of Special Conditions that required, among other things, that PSE&G implement a program to restore, enhance, and preserve a minimum of 8,000 acres of wetland adjacent to the Delaware Bay Estuary and an additional 2,000 acres of wetlands or 6,000 acres of upland buffer. The Permit further required that PSE&G impose conservation restrictions on the restored wetland and upland buffers in addition to the approximately 4,500 acres of land referred to as the Bayside Tract, located in Greenwich Township, Cumberland County, NJ.

Following issuance of the Permit, the Delaware Department of Natural Resources and Environmental Control (DNREC) challenged the terms of the Permit. PSE&G entered a settlement agreement to resolve the challenge. While PSE&G's obligations under the settlement agreement are in addition to and distinct from its obligations under the Permit, like the Permit Special Conditions, the settlement agreement addressed the protection and enhancement of aquatic biota. Among other things, the settlement agreement required that at least 2,000 of the acres of degraded wetlands to be restored under the Permit be located in Delaware and that PSE&G fund the purchase of up to 2,000 acres of additional upland buffer in Delaware.

To fulfill these requirements of the Permit and the settlement agreement, PSE&G initiated the Estuary Enhancement Program (EEP). The EEP is designed to provide an increase in detrital production of wetland areas to the marsh/estuary food web and to provide refuge, feeding habitat, and nursery grounds for various estuarine fish. PSE&G is successfully achieving the desired results through the construction of fish ladders, the restoration of diked salt hay farms, the restoration of *Phragmites*-dominated wetlands, the protection of upland buffers, and the long term preservation of ecological resources of the Delaware Bay. This Attachment focuses on the restoration of degraded wetland sites and the preservation of the Bayside Tract. While no specific activities were required at the Bayside Tract to restore wetlands, the protection offered to both the tidal wetlands and upland buffer through the Deed of Conservation Restriction (DCR) represents an important contribution to the preservation of ecological resources in the Delaware Estuary.

To fulfill the wetland restoration requirements, PSE&G selected five sites in New Jersey and five sites in Delaware for restoration (G-2 Figure 1). These sites include three previously diked salt hay farms, located in Commercial, Dennis, and Maurice River Townships in New Jersey. Normal daily tidal flow has been restored to these sites through a program of channel enhancement and excavation and dike breaching. The seven other sites are areas that, prior to restoration, were dominated by the common reed. These sites include two sites in New Jersey (the Alloway Creek Watershed and Cohansey River Watershed sites) and five in Delaware (Cedar Swamp, The Lang Tract, The Rocks, Silver Run, and Woodland Beach). Restoration at these sites consists of a program of Rodeo® and surfactant spray, followed by prescribed burns to minimize the undesirable ecological conditions associated with a *Phragmites* monoculture. Supplemental measures including marsh plain modification and source control will be implemented as appropriate for long-term control. The objectives of both types of restoration are to increase the production for the marsh/estuary food web and to provide refuge, feeding habitat, and nursery grounds for various estuarine fish.

In addition to the wetland restoration sites, the Bayside Tract provides approximately 2,585 acres of productive wetlands that contribute detritus to the marsh/estuary food web and provide refuge, feeding habitat, and nursery grounds for various estuarine fish. Approximately 1,822 acres of upland buffer areas have been preserved at the Bayside Tract to protect these aquatic resources. The upland buffer areas play an important ecosystem role in primary productivity, secondary productivity, habitat type and diversity, water quality, and water management.

The preservation of the New Jersey sites through Deeds of Conservation Restriction for the restoration sites and the Bayside Tract provide long term protection of a continuous landscape of public and private conserved open space along the Delaware Bayshore region, providing uninterrupted areas of open space and habitat beyond those associated with the individual sites. The Delaware restoration sites similarly have been protected through Declarations of Restrictions and Covenants (DRC).

In addition to the wetland restoration areas and the preservation of the Bayside Tract, PSE&G constructed and maintains six fish ladders on Delaware River tributaries that are designed to restore spawning runs of alewife (*Alosa pseudoharengus*) and blueback herring (*A. aestivalis*), collectively known as river