

**Petrified Forest National Park Puerco Sewage Lagoons
Suggestions for Rehabilitation**

Final Report

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Background

Petrified Forest National Park is currently undertaking a project involving the rehabilitation of sewage treatment facilities at several developed areas. One facet of the project includes installing vault toilets at the Puerco Pueblo Tour Stop. Thus, the sewage lagoons serving Puerco Pueblo will no longer be needed and are scheduled to be removed. The lagoons were originally installed near the Puerco River floodplain in the 1960's but never reached expected capacity use. Presently only one of the lagoons is active, and the other two are dry but occasionally hold water after precipitation events. These lagoons tend to retain water due to compacted soil and/or existing rubberized linings. To promote biodiversity in the park, management staff is interested in rehabilitating the area to provide more habitat for wildlife. Specifically, park resource managers and consulting biologists are proposing the creation of ephemeral wetland habitat (pools) from or around the old lagoons.

Due to the current paucity of persistent breeding sites for amphibians in the park and to the importance of these animals as environmental indicators (Drost et al. 1999), we recommend that the sewage pond area be specifically rehabilitated to create two types of amphibian breeding habitats, and a secondary goal of this rehabilitation will be to provide an additional reliable water source for wildlife. Herpetofauna surveys were conducted at Petrified Forest National Park between 1997 and 2002 (Drost et al. 1999, Nowak and Hart 2002, Nowak 2002). All seven species of amphibians found in the park were detected within one mile north and south of the Puerco River and sewage lagoons. It is likely that all species occur here because this area at least occasionally contains two types of critical breeding habitats for amphibians.

Ephemeral pools (defined in this report of having a hydroperiod of less than 30 days) are one type of important breeding habitat for amphibians in this area. This type of habitat, generally found in depressions in low-lying areas or artificial ponds, is scattered throughout Petrified

Forest in average summer rain years (Drost et al. 1999). Species utilizing these pools, especially spadefoot toads, have fast larval development times, sometimes as little as three weeks from egg to terrestrial form (Woodward 1983, Wilbur 1987). At least one species of spadefoot toad (New Mexico spadefoot, *Spea multiplicata*) was found breeding in ephemeral pools immediately adjacent to the sewage lagoons during the surveys (Drost et al. 1999, pers. obs.). Plains spadefoot toads (*S. bombifrons*) were heard calling nearby in or near the Puerco River.

A more rare type of habitat at Petrified Forest is relatively permanent breeding pools (defined as having a continuous hydroperiod of at least 60 days). Such pools are critical to the successful reproduction of species that take one to two months or more to develop from eggs into terrestrial forms, e.g. toads (*Bufo spp.*) and tiger salamanders (*Ambystoma tigrinum*) (Woodward 1983, Wilbur 1987). Regional draw-down of the water table and grazing-induced alterations of watercourses (e.g. Abruzzi 1995, Orodho et al. 1990) have likely decreased the availability of natural water sources to the point that amphibians with these longer larval stages now rely on artificial water sources for breeding (Drost et al. 1999, pers. obs.). Red-spotted toads (*Bufo punctatus*) have been heard calling from the sewage lagoons at the Painted Desert Visitor Center, and based on distribution patterns, it is likely that this and other toad species as well as tiger salamanders breed during some years in the unused lagoons at Puerco Pueblo (pers. obs.). These lagoons tend to retain water due to compacted soil and/or existing rubberized linings. Although these breeding areas are an artifact of relatively recent human construction, their enhancement and continued protection as amphibian breeding habitat is very important in maintaining biodiversity at Petrified Forest National Park.

Sources Used in Compiling Information for this Report

1. Published and unpublished references (see attached citations)
2. Personal contacts and interviews with amphibian, restoration, and aquatic ecology experts:
 - a. Michael Adams, Research Ecologist, USGS Forest and Rangeland Ecosystem Science Center, Corvallis, OR. 541-758-8857. Michael.Adams@usgs.gov
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General Considerations for the Sewage Pond Rehabilitation

Project Planning

Petrified Forest National Park is not proposing to return the area around the Puerco sewage lagoons to its native condition, but rather create new habitat to replicate existing natural ephemeral pools and former more permanent pool habitats in the region. Such a project would constitute more of a habitat enhancement and conversion project than a true wetlands restoration effort. However, useful guiding principles for rehabilitating this site can be gleaned from reviewing manuals of wetlands restoration and vernal pool construction (e.g. Natural Research Council 1992, USFWS 1994, De Weese et al. 1998, Ferren et al. 1998, Sutter and Francisco 1998). According to the Natural Research Council (1992), "the restoration of wetlands aquatic ecosystems has the general goal of returning the system to a close approximation of the predisturbance ecosystem that is persistent and self-sustaining (although dynamic in its composition and functioning)." They suggest the following checklist (Table 1) for project planning and restored (or rehabilitated) ecosystem analysis.

Table 1. Checklist for Wetland Restoration, or Rehabilitation. Adapted from Natural Research Council, 1992: *Restoration of Aquatic Ecosystems: Science, Technology, and Public Policy*.

A. Project Planning and Design

1. Has the problem requiring treatment been clearly understood and defined?
2. Is there a consensus on the rehabilitation program's mission?
3. Have the goals and objectives been identified?
4. Has the rehabilitation been planned with adequate scope and expertise?
5. Does the rehabilitation management design have an annual or midcourse correction point in line with adaptive management procedures?

6. Are the performance indicators—the measurable biological, physical, and chemical attributes—directly and appropriately linked to the objectives?
7. Have adequate monitoring, surveillance, management, and maintenance programs been developed along with the project, so that monitoring costs and operational details are anticipated and monitoring results will be available to serve as input in improving rehabilitation techniques used as the project matures?
8. Has an appropriate reference system (or systems) been selected from which to extract target values of performance indicators for comparison in conducting the project evaluation?
9. Have sufficient baseline data been collected over a suitable period of time on the project ecosystem to facilitate before-and-after treatment comparisons?
10. Has the project been designed to make the rehabilitated ecosystem as self-sustaining as possible to minimize maintenance requirements?
11. Has thought been given to how long monitoring will have to be continued before the project can be declared effective?
12. Have risk and uncertainty been adequately considered in project planning?

B. During Rehabilitation

1. Based on the monitoring results, are the anticipated intermediate objectives being achieved? If not, are appropriate steps being taken to correct the problem(s)?
2. Do the objectives or performance indicators need to be modified? If so, what changes may be required in the monitoring program?
3. Is the monitoring program adequate?

C. Post Rehabilitation

1. To what extent were project goals and objectives achieved?
2. How similar in structure and function is the rehabilitated ecosystem to the target ecosystem?
3. To what extent is the rehabilitated ecosystem self-sustaining, and what are the maintenance requirements?
4. If all natural ecosystem functions were not restored, have critical ecosystem components and functions been restored?
5. What lessons have been learned from this effort? Have those lessons been shared with interested parties to maximize the potential for technology transfer?
6. What was the final cost, in net present value terms, of the rehabilitation project? How cost-effective was the project?
7. Would another approach to rehabilitation have produced desirable results at lower cost?
8. What were the ecological, economic, and social benefits realized by the project?

Sutter and Francisco (1998) a summarized planning process for vernal pool ecosystem creation:

- 1) Define the target species;
- 2) Mimic the spectrum of habitat;
- 3) Define site capabilities;
- 4) Consider the entire complex and its relationship to its surroundings;
- 5) Consider long-and short-term management.

The first step in this project will be for the park management, project contractor, and contributing biologists (the “rehabilitation team”) to prioritize goals and objectives for the sewage pond rehabilitation. Goals and objectives should clearly state descriptions of the desired function(s) of the pool ecosystem(s) when completed. Goals might include creating two types of amphibian breeding habitat (temporary and more permanent), restoring water quality, hydrology, stability, and types of (temporary and more permanent) pool flora and fauna. Objectives could include the shape, size, and depth of the reconstructed pools, specific characteristics of water quality to be achieved, pool persistence, species composition of the various communities of aquatic biota and flora expected, and the expected composition of species visiting the pools.

The second step will be for the rehabilitation team to develop evaluation criteria based on repeatable performance indicators to determine to what extent the objectives are being achieved (after Natural Research Council, 1992). These performance indicators will be incorporated into a long-term monitoring program to assess the health and functioning of the pool ecosystems over time. A realistic sampling schedule for the indicators needs to be set up with either contracting biologists or park staff responsible for carrying out the sampling. Monitoring must be maintained long enough for the park managers to confirm that the pool rehabilitation can withstand stochastic environmental events such as 100-year floods and multi-year droughts. Adequate funding must be secured to guarantee long-term monitoring and maintenance of the pools by park staff and/or consultants.

As well, land uses adjacent to the project should be reviewed for potential disturbances or other effects of interactions, including hydrological connections. In the case of the Puerco sewage lagoons, this could include disturbance from local developed tourist areas, (potentially), flooding from the Puerco River, or maintenance activities on the water line. Based on past experience, disturbance of this type can be minimized by involving and/or informing every current and to-be-hired person on the park staff of the project goals, objectives, schedule of events, and physical scope and extent (including non-visible elements, e.g. water lines).

Evaluating the Success of Rehabilitation

The general purpose of evaluating an aquatic ecosystem rehabilitation project is to determine how effective the reconstruction attempt was in replicating the target ecosystem. The evaluation should define the problem, specify what data are to be collected and when, and explain how the data are to be used once collected. Summarizing remarks by the Natural Research Council (1992), De Weese (1998) and the USFWS (1994): “Evaluation must include procedures for synthesizing monitoring data. Because rehabilitation strives to alter an existing ecosystem so that it becomes more similar to a predisturbance model or reference pool, the evaluators need to

gather a comprehensive data set relating the restored system to the antecedent one in biological, physical, and chemical terms. A broadly representative range of assessment criteria must be used to reflect the major dimensions of the ecosystem, including its food webs, habitat heterogeneity, and dynamic physical, chemical, and biological processes. Thus, thorough evaluation of rehabilitation may necessitate that the resulting body of basically incomparable or unrelated data be reduced to manageable terms. One solution is to strategically select assessment criteria that suggest the presence of a host of other complex desired ecological states". For example, the presence of neotenic salamanders (aquatic adults that never become terrestrial) in a more permanent pool would indicate unqualified success on several fronts: persistence of water sufficient for the forms to develop (over a few years), persistence of prey base to support the adults, and initial successful breeding of local terrestrial adults. For the more temporary pool, the artificial pool near the Haystacks could serve as a reference.

According to the Natural Research Council (1992), the US Fish and Wildlife Service (1994), and De Weese (1998), evaluation criteria (i.e., performance indicators) should include both structural and functional attributes of the ecosystem, and should take into account both temporal variation and spatial heterogeneity. They should be based on known conditions of the hypothetical reference ecosystem, e.g. other pools in the Little Colorado River drainage system or in the Four Corners area. These indicators should be linked to specific project objectives. Potential criteria include:

- 1) Persistence of pools. Measures include water depth, number of days the pools have water, diameter of wet zone surrounding the pools, etc.
- 2) Water quality both on and off the project site, wherever affected by the restoration. Measures include dissolved oxygen, dissolved salts, dissolved toxics and other contaminants (this could be important in ascertaining that all sewage pond contaminants have been properly removed), floating or suspended matter, pH, odor, opacity, temperature profiles, etc.
- 3) Soil condition. Measures include soil chemistry; erodibility; permeability; organic content; soil stability; and physical composition, including particle sizes and microfauna.
- 4) Hydrology, including quantity of discharge on annual, seasonal, and episodic basis; timing of any discharge; surface flow processes, including velocities, turbulence, shear stress, and exchange processes; ground water flow and exchange processes; retention times; and particle size distribution.
- 5) Topography and morphology as indicated by surface contours; the relief (elevations and gradients) and configuration of site surface features, including subsurface features; and project shape, form, and size and location in the watershed, including position relative to similar or interdependent ecosystems.
- 6) Flora and fauna. Measures include absolute and relative vegetative cover, species composition, population density, diversity, growth rates, longevity, species integrity (presence of full complement of indigenous species found on the site prior to disturbance), productivity, stability, reproductive vigor, size- and age-class distribution, presence of non-native species, incidence of disease, genetic defects, and elevated body burdens of toxic substances.

- 7) Nutrient availability and flux patterns. Measures include whether the ecosystem is gaining or losing nutrients, and whether the nutrient flux is comparable to that in hypothetical pools.
- 8) Provision of shelter for pool users (e.g., from sun, wind, rain, or noise).

Reducing Risk of Failure

The problems encountered during rehabilitation may include every aspect of construction—site selection, topographic contouring, transplantation, inadequate nutrient supplies for plant or animal growth, and pest invasion. The Natural Research Council (1992) lists several different reasons for restoration failure: 1) careless implementation of restoration projects, e.g. when a contractor disregards engineering or horticultural specifications; 2) the project designer's knowledge proves inadequate to produce a functional restoration design; 3) objectives and criteria are not established prior to the project, so the project lacks assessment criteria to judge progress and to catch warning signs of impending failure, and to provide for mid-course corrections if plans fail to achieve their intended results; and 4) no attempt is made to relate individual, piecemeal restoration efforts to broader hydrologic and ecosystem management goals.

The Council proposes the following ways to reduce failure risks during rehabilitation:

- 1) More detailed assessment of function prior to rehabilitation
- 2) More detailed plans
- 3) Higher standards for success
- 4) More expertise
- 5) Larger buffer zones
- 6) More detailed and longer-term surveillance and monitoring
- 7) Greater midcourse correction capability
- 8) Longer-term and greater maintenance responsibilities
- 9) More detailed reports with broader distribution
- 10) More funding

All of these factors should be considered when designing and reviewing proposals for rehabilitating the Puerco sewage lagoons.

Specific Ideas for Rehabilitating the Puerco Sewage Ponds

Desired Biological Functions of the Rehabilitated Pools

The stated goal of this project is to rehabilitate the existing Puerco sewage ponds to increase biodiversity in Petrified Forest National Park, specifically by recreating two types of amphibian breeding habitat through two types of pools. One type of reconstructed pool would preferably contain water at least six months of the year, from spring to fall, while the other pool type would only need to contain water during the summer monsoon period (July to September).

The Natural Research Council (1992) recommends that “the rehabilitation of a site should be considered in a regional context, and the area that will be available to reestablished wildlife communities should be considered in relation to the size and longevity of the organisms that will occupy the site. Restoration of a vernal pool may be viewed in the context of its local watershed or with respect to the distribution of its main species.” This project will recreate two types of breeding habitat for amphibians, and so suitable habitat conditions must also be provided for the development of their eggs (emergent vegetation) and for their larvae’s potential prey items (invertebrates, phyto-, peri- and zoo-plankton, and algae) (Woodward 1983, Taylor et al. 1987, Wilbur 1987, Schneider and Frost 1996). However, it is likely that the pools will be used by other species and the rehabilitation team should decide a priori which other wildlife and plant species should be encouraged to use or live in the pools (and which should be discouraged), based on regional availability of similar alternate habitats.

The more permanent pool(s) would contain water deep enough, and long enough (several months), to allow metamorphosis of tiger salamander and true toad larva. The preferred shape of the pool would be such that the center would be deeper, and the edges shallow with native emergent or submerged vegetation such as graminoids (grasses, rushes, and sedges), pondweeds (*Potamogeton* spp.), and algae species. These plants provide important cover for larval amphibians and their prey as well as points of attachment for amphibian egg clusters. Plant detritus blown in from the edges of the pool will also provide natural attachment sites for egg clusters (pers. obs.). The edges of the pool could be planted with native woody species such as cottonwoods (*Populus fremontii*), willows (*Salix exigua* or *gooddingii*), rushes (*Juncus bufonius*) and/or sedges (*Cyperus* spp. or *Schoenoplectus* spp.) (Hansen et al. 2003). These species will provide cover for other wildlife species such as deer, small mammals, and birds that may also use the pool, primarily for drinking. Use by a high diversity of vertebrate wildlife species is a secondary functional goal of this pond.

The more ephemeral pool(s) would provide breeding habitat for spadefoot toads. These pools would only need to hold a few inches to a foot of water consistently during the summer rainy period. It would be desirable for them to be dry for at least a few months of the year to prevent establishment of amphibian predators such as fish (J. Stuart, P. Rosen, C. Schwalbe, B. Bury, pers. comm.). No bankside plantings would need to be made for this type of breeding habitat, but encouragement of suitable native annual plants in the ponds would promote healthy ecosystem function (Bliss and Zedler 1998, De Weese et al. 1998).

Within both pool types, a desired functional goal is self-sustained aquatic invertebrate and algae communities that provide the basis of a food web where amphibian larvae are top consumers. Larval salamanders in temporary pools in California have been documented to eat the following invertebrates: cladocerans, chironomid larva, ostracods, and fairy shrimp (Taylor et al. 1988). They may also eat *Spea* tadpoles (Woodward 1983). Larval amphibians eat primarily algae (including periplankton). They also occasionally eat small invertebrates and (in the case of spadefoot toads) each other (Pfennig 1990, Wilbur 1987). Western spadefoot toads (*Spea hammondi*) have been documented to eat fairy shrimp in particular (B. Haas, pers. com.).

The plant and animal community composition and persistence of vernal pools are complexly influenced by the original species introduced, the rate of drying of the pools, competition, and predation (Woodward 1983, Wilbur 1987, Taylor et al. 1987, Schneider and Frost 1996, Morey 1998). For example, Woodward (1987) found if larval tiger salamanders are present in longer-lasting temporary ponds, the survival of spadefoot tadpoles is greatly reduced because that species is eaten by the salamanders. When spadefoot and true toad (*Bufo*) tadpoles occur in the same ponds, in most cases *Spea* will outcompete *Bufo* tadpoles. However, when tiger salamanders are introduced, the survival of the true toads often increases. The survival of *Spea* tadpoles is also influenced by the density of their and of other species of tadpoles in the same pool, and by the drying rates of the pools (Wilbur 1983). If high densities coincide with fast drying rates, or in some cases, if fairy shrimp are consumed as prey items, spadefoot tadpoles may turn cannibalistic (Pfennig 1990). This releases predation pressure on their microinvertebrate and phyto- or periplankton prey, which may (temporarily) enjoy greater survival and reproductive success. On the other hand, Blaustein (1997) found that the simple presence of salamanders in pools changes the reproduction rate and hatching success of their crustacean prey (cladocerans, copepods, and clam shrimp), likely through chemical cues.

An initial goal of this project will be to build up amphibian populations to levels where all age classes are well-represented. This will likely take three to five or more years for tiger salamanders and true toads. After this, the success of annual breeding event will matter less; individuals hatched in any given year may not survive (i.e. if the pools dry up), but the populations will persist (T. Graham, pers. comm.).

Also in both pool types and in the restoration area as a whole, a desired functional goal will be to prevent non-native species from becoming established. To achieve this goal, constant monitoring will be necessary.

Rehabilitation Plan and Considerations

Site Rehabilitation. Generic techniques for restoring or rehabilitating wetlands include: 1) reestablishing or managing wetland hydrology; 2) eliminating or controlling chemical or other contaminants affecting wetlands; and 3) reestablishing and managing native biota (may include control of nuisance species) (Natural Research Council 1992). The US Fish and Wildlife Service (1994) recommends specific techniques for vernal pool restoration, which the following plan generally follows.

In general, restoration (in this case rehabilitation) of vernal pools involves the scraping of shallow impoundments where soils already have a clay layer to retain rainwater. This is likely the soil condition at the Puerco sewage ponds. At the Puerco sewage ponds, we must first remove contaminants associated with the sewage. This will include liquid or solid materials left in the ponds, the rubberized pond linings, and will likely some topsoil associated with the ponds. These materials will need to be removed to a suitable containment site (the USFWS [1994] recommends that all excavation spoil piles be removed).

The ponds will then need to be recontoured using the existing native and fill soils. Each pool should maximize rainwater retention through its shape and adjacent landscape sloping (T. Graham, USGS Canyonlands Field Station, pers. comm.). The soil in the new ponds (or at least the most permanent pond) will likely need to be modified through compaction, addition of clay materials, or the pond lined to facilitate water retention. De Weese (1998) cautions against over-compaction of the soil as it may not permit cracks to form, which tiger salamanders and spadefoot toads may use for aestivation. Some provision will need to be made for fast draining of the ponds if necessary in the future such as the installation of gated culverts to gravity-drain the water. However B. Haas (pers. comm.) suggests that draining could be accomplished effectively via a centrifugal pump. For monitoring water depth, the USFWS (1994) recommends installation of two hydrology staff gauges in each pool for deep and shallow water level monitoring. They also recommend keeping photographic records of each pool.

One model for the rehabilitation that has been proposed consists of two pools, one deeper and more permanent oasis, and one more ephemeral pool (B. Haas, pers. comm.). Of the existing three ponds at the sewage pond site, the center pond would be filled in. It seems most efficient to work with the existing pond structures and topography, and have the existing northern-most sewage pond be converted to the more permanent pool, and retain the most southern pond as a more ephemeral pool. The more permanent pool may drain through a developed connection into the more ephemeral pool, or they may be kept separate. Another option is to create an intermittent stream channel between either of the pools (likely the more permanent one) to the Puerco River (B. Haas, pers. comm.). This channel would be constructed to resemble an intermittent stream rather than a roadway through the placement of rocks and through contouring. It would run through the dunes to the Puerco River through the area of lowest topographical relief. The potential for immigration and emigration of native species between the river and the breeding pools would be enhanced, and it would also encourage natural flooding (and inoculation) of the pools (T. Graham, pers. comm.). If a stream channel option is chosen, special consideration must be given to keeping it from becoming a conduit for exotic species to move between the pools and the Puerco River, or vice versa.

The adjacent water line and valves could be tapped to provide initial water to the ponds, or as needed to maintain desired water levels. At least one of the rehabilitated pools should be allowed to function as a completely natural system. It should not require any input of water other than from precipitation or possibly overflow from the more permanent pond. However, it is possible that if the rehabilitation is attempted during prolonged drought conditions that it will take the recurrence of a good rain year for the pools to fill and/or retain water as desired. The second, more permanent pool should be maintained to contain water for at least 60 days (Morey 1998).

Establishment of Flora and Fauna. Ecologists predict that early succession communities dominated by short-lived plants should be easiest to restore (Natural Research Council 1992), and this is the type of community that will dominate the rehabilitated sewage pond area. We will also plant some longer-lived perennial species but these are already well-established in the area. We predict that their establishment will be aided by the presence of ground water close to the surface due to the nearby Puerco River channel. The more ephemeral pool will likely be

dominated by annual plants, as this type of community is common in vernal pools of the southwest US (De Weese et al. 1998, Ferren et al 1998).

To some degree, we expect that the establishment of a native fauna and flora in the pools will occur naturally from invading local sources (e.g. McCormick et al. 1987, Zedler and Black 1992). Small species and/or their eggs will likely be carried in by migrating birds and insects or the wind (Silveira 1998, T. Graham, USGS Canyonlands Field Station, pers. comm.). Zedler and Black (1992) found that some plant species are carried in to temporary pools as seeds in the droppings of rabbits which visit the pools to drink. Large mobile herbivores like rabbits are common at Petrified Forest so this type of vector mechanism must not be discounted. Appendix A lists selected vertebrate species known to inhabit or migrate through the Puerco sewage pond area. None of these species will need to be encouraged to utilize the pools since they already exist in the area, and all may use the rehabilitated pools.

Although the ultimate goal of rehabilitation should be a self-sustaining ecosystem, some management (or control) may be necessary in the initial phase of restoration (e.g., stabilizing hydrology to assist in plant community establishment) (Natural Research Council 1992). Several scientists interviewed for this report recommended inoculating or "seeding" (bringing in from another source) the rehabilitated pools with aquatic invertebrates, phyto-, peri-, and zooplankton, and/or plants from nearby similar water sources (such as the Puerco River or temporary pools) (see also Ferren et al. 1998). Microflora and fauna are usually introduced through the plankton collections via dip net and water column sampling, and/or through the collection of soil in dried or active pools. These techniques are well-accepted for providing temporary pools with "starter" plant and animal communities (B. Haas, Varanus Biological Services, pers. comm., Wilbur 1987, Bliss and Zedler 1998). Inoculation may occur directly or via soil from local dry temporary pools (e.g. Blaustein 1997). Table 2 lists several such species and their expected function in or around the pools.

The scale of genetic variation is an important but little-known factor affecting restoration efforts. It is most appropriate to select plants and animal material from local sources by sampling broadly within those populations. However, even then the genetic variation between organisms at different pools (especially temporally or spatially isolated vernal pools) may be very divergent (King et al. 1996). Alternatively, with vegetatively or asexually reproducing organisms, there is a risk that sites will be dominated by single clones vulnerable to extinction if catastrophic environmental events or disease outbreaks occur in the rehabilitation site (Natural Research Council 1992).

Table 2. List of selected plant and animal species that may be specifically seeded in newly-created pools rehabilitated from the Puerco sewage pond area at Petrified Forest National Park. See text for references and personal contacts used to compile this list

COMMON NAME	SCIENTIFIC NAME	FUNCTION
Vascular Plants		
Cottonwood	<i>Populus fremontii</i>	permanent cover and habitat for vertebrate species, shade
Willow	<i>Salix exigua or goodingii</i>	bank stabilization, permanent cover and habitat for vertebrate species, shade
Sedges and Rushes	<i>Juncus spp. and Cyperus spp. or Schoenoplectus spp.</i>	cover and oviposition sites, bank stabilization
Non-vascular plants		
Algae		food for primary consumers, cover, oviposition sites
Phyto- and periplankton		food for primary consumers and tadpoles
Invertebrates and others		
Fairy shrimp	<i>Branchinecta lindahli</i> <i>Streptocephalus dorotheae</i> <i>Thamnocephalus platyurus</i>	Food for primary and secondary consumers
Tadpole shrimp	<i>Triops newberryi</i> and others	"
Water fleas	Order Cladocera	"
Chironomid larvae		"
Copepods	<i>Daphnia spp.</i>	"
Clam shrimp	<i>Eulimnadia cylindoba</i> and others	"

More than one inoculation may be necessary if the desired flora and faunal communities do not become established within a few years, especially if current drought conditions persist (e.g. Wilbur 1987, De Weese 1998). However, annual reseedling will likely not be necessary in the more ephemeral pool once populations become established, due to the ability of vernal pool invertebrates and seeds to persist over long periods by becoming dormant (Williams 1998, Bliss and Zedler 1998). In fact, at least one vernal pool scientist interviewed felt that purposeful inoculations would not be necessary to establish native populations of small plants and aquatic animals due to the propensity of vernal pool species to quickly colonize new areas (T. Graham, pers. comm.).

Disturbance and Exotic Species. According to the Natural Research Council (1992), "The scale of the rehabilitation must be adequate to account for spatial heterogeneity of habitat and for interactions between the target system and its surrounding landscape. The project area needs to be large enough to limit deleterious effects that boundary conditions may impose on interior aquatic functions. Project managers must be able to exert influence over zones in which major causes of ecological disturbance to the project are occurring, so that the disturbance can be controlled or eliminated." One potential major cause of ecological disturbance in the rehabilitated pools that comes immediately to mind is trespass cattle. For these pools to function properly as a native ecosystem, we feel that cattle must be kept out (although Silveira [1998] lists examples in which their grazing may have useful effects in controlling exotic plant species, the damage to the pools from trampling may outweigh such a benefit). While the current fence along the Puerco River appears to keep cattle out of this section, it might also be useful to construct a secondary deer- and antelope-friendly fence immediately around the pools. Elk appear to be moving through the Puerco River corridor in greater numbers in recent years (pers. obs.), and their use of the pools should be monitored to make sure that they are not also having deleterious effects through bank destabilization and vegetation removal (S. Tuttle, NRCS, pers. comm.).

Scientists interviewed during this research phase were very concerned about the potential for introduction of exotic species into the pools, and stressed the need to plan for, monitor, and ultimately redress such impacts (Kats et al. 1988, M. Adams, B. Bury, P. Rosen, Cecil Schwalbe, M. Sredl, and J. Stuart pers. comm.). In the southwestern United States, we are particularly concerned with exotic fish (e.g. mosquito fish, *Gambusia affinis affinis*, bluegill, *Lepomis macrochirus*, and green sunfish, *Lepomis cyanellus*), crayfish (e.g., red swamp crayfish, *Procambarus clarkii* and virile crayfish, *Orconectes virilis*), bullfrogs (*Rana catesbeiana*), and certain invertebrates (e.g., New Zealand mudsnails, *Potamopyrgus antipodarum*, and the possible introduction of zebra mussels, *Dreissina polymorpha*) (Kats et al. 1988, Nowak and Santana-Bendix 2002, Woodward 1983, B. Haas, pers. comm.).

One of the most common vectors of vertebrate introductions in aquatic systems is humans. Humans introduce non-native fauna (fish, bullfrogs, turtles, etc.) through fishing or by deliberately freeing captive animals (P. Rosen, University of Arizona, pers. comm.). There is already a strong tradition of releasing such animals in national parks (pers. obs.). While it will not be feasible to keep all humans out of the pools, signs describing the project and potentially negative effects of introducing exotic species could be erected around the ponds to minimize this threat. The potential for exotic animal introductions via their own power (e.g. bullfrogs and crayfish) or as hitchhikers on other animals (e.g. crayfish, other invertebrates, plants, and small fish are known to disperse on the legs of wading birds and dragonflies) will be harder to control.

The pools must be surveyed several times a year to catch introductions as soon as possible after they occur. Scientists interviewed concurred that logistically, there must be a way for the pools to be drained should bullfrogs or fish become established. For fish and bullfrogs, hand-trapping adults and then draining the pools will suffice in removing the species. Removal methods for crayfish and other invertebrates are much more difficult, as the animals are capable of hiding out in burrows deep in the mud for long periods of time (B. Haas, P. Rosen, pers. comm.).

The susceptibility of a site to invasion by exotic or undesirable plant species is also of primary concern because aggressive plant species such as cattail (*Typha domingensis*), water milfoil (*Myriophyllum sp.*), and tamarisk (*Tamarix chinensis*) may dominate sites intended for other vegetation (Natural Research Council 1992, Hansen et al. 2003). Cattails may need to be removed if they become so numerous that they are in danger of converting the pools to dry meadows (T. Graham, pers. comm.). Plants on the edges of the pools may need to be hand-pulled every year (e.g. Russian thistle, *Salsola tragus*) or removed using more extreme measures (burning or chemical) if they become established (e.g. tamarisk) (Pollak and Tan 1998).

Permits. There is currently an environmental assessment (EA) being completed for the removal of the sewage ponds (K. Beppler-Dorn, Petrified Forest NP, pers. comm.). According to John Collins, NPS Regional Public Health Consultant, there are no further federal permits required, although the replacement (septic) system must be operational before the lagoon can be decommissioned. He strongly recommends letting the remaining sewage sludge dry before attempting removal, due to the cost [and mess] associated with removing wet materials. The dried sludge and liners must be removed to a state or local landfill site that accepts such materials.

Archaeological clearance may be necessary for this project, especially if an option is adopted that includes running a channel from the sewage lagoon area to the Puerco River.

The Arizona Department of Environmental Quality's (ADEQ) Greg Brown (pers. comm.) stated that no specific permits were required to remove sewage sludge or linings or for the pond rehabilitation. However, a septic permit must be obtained for the new Puerco Pueblo Tour Stop vault toilets, preferably before the lagoons are decommissioned. In addition, official notification must be made to the ADEQ for the lagoons' closure under the terms of the original permit. The notification must include the date and plan for closing the sewage lagoons. If the lagoons were permitted under a general permit, notification may be made within 30 days of the closure. If the lagoons were permitted under an aquifer protection plan, the notification must occur and be approved by the ADEQ before the lagoons can be closed.

For further information on these issues, contact the following people:

Arizona Department of Water Quality
Greg Brown
Wastewater Permits Division
800-234-5677 or

www.sosaz.com/Rules_and_regulations.htm and go to Title 18, Chapter 9 in the Table of Contents

National Park Service Intermountain Region
John Collins
Regional Public Health Consultant
john_collins@nps.gov
303-969-2922

Trinkle Jones
Western Archaeological Clearance Center
Tucson, AZ
520-670-6501 x. 239

Contractor Interested in Rehabilitating the Puerco Sewage Ponds

Mr. William Haas, Principal Biologist with Varanus Biological Services (San Diego, California and Fort Collins, CO) is a wetlands restoration consultant and amphibian breeding ecology expert. He has expressed interest in subcontracting the sewage pond rehabilitation work. He may be able to secure additional matching funding for this project through a grant from a non-profit organization such as the Partners in Amphibian and Reptile Conservation (PARC) or the Five-star Restoration Challenge Grant Program. If requested by park staff, he will submit a detailed rehabilitation plan for the Puerco sewage lagoons following the recommendations of this report.

Mr. Haas was the Principal Investigator and Design Coordinator for the restoration or rehabilitation of eight vernal pools in southern California. The purpose of this vernal pool restoration was primarily the recovery of western spadefoot (*Spea hammondi*), a California Species of Special Concern. His responsibilities included pool redesign (contours, pool limits, depth, etc.) and rehabilitation of pools affected by use of park patrons (hikers, bicyclists, etc.). Subsequent activities included marking pool limits (with signage and barriers) and inoculating pools with common flora and fauna of adjacent pools.

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Appendix A. Vertebrate Species Documented Near the Puerco Sewage Lagoons at Petrified Forest National Park.

Vertebrate species documented near the Puerco sewage lagoons at Petrified Forest National Park, Arizona. Compiled from: Ramotnik and Bogan 1998, Drost et al. 1999, Nowak and Hart 2002, Nowak 2002, and personal observations.

Mammals

Fringed Myotis (*Myotis thysanodes*)
Yuma Myotis (*Myotis yumanensis*)
Pallid Bat (*Antrozous pallidus*)
Plains or Apache Pocket Mouse (*Perognathus flavescens apache*)
Silky Pocket Mouse (*Perognathus flavus*)
Brush Mouse (*Peromyscus boylei*)
Deer Mouse (*Peromyscus maniculatus*)
White-footed Mouse (*Peromyscus leucopus*)
Pinyon Mouse (*Peromyscus truei*)
Western Harvest Mouse (*Reithrodontomys megalotis*)
White-throated Woodrat (*Neotoma albigula*)
Ord's Kangaroo Rat (*Dipodomys ordii*)
Botta's Pocket Gopher (*Thomomys bottae*)
Desert Cottontail (*Sylvilagus audubonii*)
Porcupine (*Erethizon dorsatum*)
Coyote (*Canis latrans*)
Elk (*Cervus canadensis*)
Mule Deer (*Odocoileus hemionus*)
Pronghorn (occasional) (*Antilocapra americana*)

Birds (partial list, excluding water birds)

Great Blue Heron	Horned Lark
Green Heron	Loggerhead Shrike
Snowy Egret	Northern Flicker
Great Egret	Red-napped Sapsucker
Red-tailed Hawk	Olive-sided Flycatcher
Cooper's Hawk	Western-Wood Pewee
Sharp-shinned Hawk	Hammond's Flycatcher
Golden Eagle	Dusky Flycatcher
Great Horned Owl	Cordilleran (Western) Flycatcher
Western Screech Owl	Black Phoebe
Long-eared owl	Say's Phoebe
Killdeer	Ash-throated Flycatcher

Birds con't.

Western Kingbird	Yellow Warbler
Cassin's Kingbird	MacGillivray's Warbler
Plumbeous (Solitary) Vireo	Wilson Warbler
Warbling Vireo	American Redstart
Rock Wren	House Finch
Ruby-crowned Kinglet	Lesser Goldfinch
Blue-gray Gnatcatcher	Mountain Chickadee
Cedar Waxwing	Cassin's Sparrow
Common Raven	Baird's Sparrow
European Starling	Rufous-crowned Sparrow
Tree Swallow	White-crowned Sparrow
Violet-green Swallow	Dark-eyed Junco
Northern Rough-winged Swallow	Black-headed Grosbeak
Orange-crowned Warbler	Blue Grosbeak
Nashville Warbler	Lazuli Bunting
Audubon (Yellow-rumped) Warbler	Brown-headed Cowbird

Water Birds (partial list) (these species have been seen on water bodies in the park and thus are likely at the Puerco lagoons)

Eared Grebe	Northern Pintail
Western Grebe	Blue-winged Teal
Pied-billed Grebe	Ring-necked Duck
American White Pelican	Franklin's Gull
White-faced Ibis	Herring Gull
Mallard	Ring-billed Gull
American Wigeon	American Avocet
Northern Shoveler	Willet
Cinnamon Teal	Lesser Yellowlegs
Bufflehead	Spotted Sandpiper
Ruddy Duck	Whimbrel
Canada Goose	Baird's Sandpiper
Green-winged Teal	Wilson's Phalarope

Reptiles

Side-blotched Lizard (*Uta stansburiana*)
Eastern Fence Lizard (*Sceloporus undulatus*)
Lesser Earless Lizard (*Holbrookia maculata*)
Collared Lizard (*Crotaphytus collaris*)
Plateau Striped Whiptail (*Cnemidophorus velox*)

New Mexican Whiptail (*Cnemidophorus neomexicanus*)
Common Kingsnake (*Lampropeltis getula*)
Glossy Snake (*Arizona elegans*)
Gopher Snake (*Pituophis catenifer*)

Amphibians

Tiger Salamander (*Ambystoma tigrinum*)
Woodhouse Toad (*Bufo woodhousei*)
Red-spotted Toad (*Bufo punctatus*)
Great Plains Toad (*Bufo cognatus*)
Plains Spadefoot (*Spea bombifrons*)
Southern Spadefoot (*Spea multiplicata*)
Couch Spadefoot (*Scaphiopus couchii*)
