LONG-TERM EFFECTS OF WASTEWATER IRRIGATION ON FORESTED ECOSYSTEMS AT PENNSYLVANIA STATE GAME LANDS 176

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Abstract—In 1983, the Pennsylvania State University engaged in a spray irrigation system for the disposal of treated wastewater on 209 hectares of farm and forest land in State Game Lands 176. The system was designed to distribute 5 centimeters of wastewater 52 weeks per year. Differences in species composition and structure have been observed between the irrigated and non-irrigated. In 1997, to monitor the long-term effects of wastewater irrigation on plant community and soil conditions in forested ecosystems, 20 pairs of irrigation and non-irrigation plots were established, and density and species composition of tree, shrub, and herbaceous plants were inventoried. Soil samples of A and B horizons were also taken for each 20 x 20 meters plot. At each plot, plants components included (1) overstory stems on 20 x 20 meters plot, (2) sapling-sized stems on four 10 x 10 meters subplots, (3) seedling-sized stems on four 2 x 2 meters subplots, (4) shrub species coverage on four 10 x 10 meters subplots, and (5) herbaceous plants coverage on sixteen 1 x 1 meters subplots. Initial results indicate striking differences in species composition, in densities of trees and shrubs, and in shrub and herbaceous coverage values, between the irrigated and non-irrigated forested communities. Total numbers of combined tree and shrub species in the non-irrigated overstory, sapling-sized, and seedling-sized components were 15, 47, and 33 species, respectively, compared to 17, 29, and 10 species, respectively, for the irrigated components. Overstory, sapling-sized, and seedling-sized stem densities were 536, 2,823, and 107,316 stems/hectares, respectively, for the non-irrigated and 361, 706, and 1,127 stems/hectares, respectively, for the irrigated components. Shrub and herbaceous coverage values were 17 and 80 percent, respectively, in the irrigated area, compared to 61 and 30 percent, respectively, in the non-irrigated area. The fertility levels in soil A and B horizons were also very different for the two areas. For both A and B soil horizons, the irrigated area had higher pH, higher phosphorus, magnesium, and calcium contents, and lower exchangeable acidity than the non-irrigated area. These data suggest that modifications to either the plant community species base or the methods of wastewater distribution will be needed to maintain forested ecosystems in the wastewater irrigation area of State Game Lands 176.

INTRODUCTION

Disposal of sewage effluent has become a problem for many municipalities due to population increases and stricter regulatory controls. Typically, wastewater from sewage treatment plants is discharged into rivers or lakes. However, this disposal method has often lead to environmental problems through the eutrophication of aquatic systems. An alternative method, disposal on land, has the potential advantages of reducing stream pollution and recharging ground water reserves (Sopper and Kardos 1973). Effluent disposal experiments conducted in forested areas have shown that spray irrigation with chlorinated sewage effluent caused changes in the structure and species composition of vegetation. Increased rate of tree growth, increased plant biomass, altered species composition of ground-level plants, and decreased production and survival of native shrub and tree species have been brought about by the addition of nutrients and water to soil and by ice damage during winter (Brister and Schultz 1981, Epstein and Sawhill 1977, Sopper and Kardos 1973).

In 1983, the Pennsylvania State University engaged a spray irrigation system for 209 hectares of farm and forest land managed by the Pennsylvania Game Commission (State Game Lands 176). The system is designed to distribute 5 centimeters of wastewater 52 weeks per year. About one-half of the current forest land was always forest land, whereas the other half had been used for agriculture. No actual inventories of the shrub and tree species composition and structure have been conducted, but there has been an observed difference between irrigated and non-irrigated areas. Observations suggested there has been increased mortality of the trees in the overstory of irrigated areas as compared to non-irrigated areas. It has also been observed that the understory of the irrigated forests has more herbaceous plants and fewer shrub and tree species stems than the nearby non-irrigated forests. Actual changes that have occurred to the areas that would be different from normal stand development are unknown. However, it is possible to compare the present conditions in similar irrigated and non-irrigated forests and to measure future changes in these two conditions. A project has been started to determine the long-term effects of wastewater irrigation on forested ecosystems by establishing and maintaining a program to monitor plant community and soil conditions in irrigated and non-irrigated forested areas. Results from the initial inventories are presented in this paper.

METHODS

The study area was located in central Pennsylvania, 2 kilometers north of State College. The gently rolling terrain was in the Ridge and Valley region (Lull 1968) on lands managed by the Pennsylvania Game Commission. The soil was Morrison sandy loam (Ultric, Hapludalf; fine, loamy,

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mixed, mesic). Site quality was about average, and if occupied by evenaged mixed oak stands, the site index would be about 65.

Ideally the sampling procedures and design would have been prepared prior to treatment but the effects of wastewater irrigation on forested ecosystems was not a concern in 1983. In July 1997, 20 pairs of irrigation and non-irrigation long-term monitor plots were established to inventory density and species composition of the tree, shrub and herbaceous plants in forested areas. The plots were paired on the basis of having similar physical site conditions, history of use, and perceived species conditions in 1983 when the irrigation system was engaged. Reasons for some forested areas to be irrigated and others not irrigated were only due to the design features of the irrigation network. Plots were established and inventoried according to the Storm and Ross (1992) protocol for monitoring vegetation on public lands. A total of 40, 20 x 20 meters permanent plots were used to inventory the overstory trees and shrubs. Species, diameter (at 1.3 meters above ground in centimeters), health class (healthy, dead, or injured), and type of injury (branch breakage, stem breakage, or stem decay) of all overstory stems (≥11 centimeters in diameter) were recorded. Each 20 x 20 meters plot was subdivided into four 10 x 10 meters subplots to acquire species and diameter of all sapling-sized stems and shrub coverage. Nested within each 20 x 20 meters plot were four 2 x 2 meters subplots, each located 5 meters from plot center along cardinal directions, to inventory abundance of seedling-sized stems. Each 2 x 2 meters subplot was further subdivided into four 1 x 1 meters subplots to inventory coverage of herbaceous groups (grass, broadleaf, moss, vine). A randomly selected soil sample was also taken from near the center of each plot. Soil from the A (0-4 cm below humus layer) and B (10-25 cm below humus layer) horizons was analyzed for pH, extractable phosphorus (kilograms/hectare), exchangeable calcium, magnesium, potassium and cation exchange capacity.

Analysis of variance was used to test for significant differences between irrigated and non-irrigated areas in mean (1) number of species, density, basal area and stocking of overstory stems,(2) number of species and density of sapling-sized stems, (3) number of species and density of seedling-sized stems, (4) shrub species and coverage, (5) herbaceous coverage, and (6) soil chemical properties. Significance at the 0.05 level was used in all cases. Using analysis of variance to test for significance between sample plots selected after treatment violates basic design requirements. However, the analyses were conducted to provide an expression of variability about mean values.

RESULTS AND DISCUSSION

Overstory Stems

A total of 17 tree species were inventoried on the 20 paired permanent overstory plots, with the irrigated and non-irrigated areas containing 15 and 13 species, respectively. There was no significant difference in number of tree species per plot between irrigated (4 species/plot) and non-irrigated (5 species/plot) areas (Table 1). Tree density (Table 1) in the non-irrigated area (531 stems/hectare) was significantly different from the irrigated area (355 stems/hectare). The non-irrigated area had more aspen (see Appendix 1 for scientific names), black cherry, and pine stems than the irrigated area (Table 2). Oak, red maple, and other trees were equally abundant in both areas. The irrigated area had more ash and hickory stems than the non-irrigated area, but the numbers of ash and hickory were low for both areas. The irrigated area (Table 3) had a lower proportion of healthy trees (64 percent) and a higher proportion of injured trees (29 percent) than the non-irrigated area (84 percent healthy and 9 percent injured). These data indicate poor health in the overstory of the irrigated area. Basal area (27 meters^2/hectare) and stocking (100 percent) were significantly greater in the non-irrigated area (Table 1) than in the irrigated area (19 meters^2/hectare basal area and 73 percent stocking).

Overstories in both the irrigated and non-irrigated areas had low numbers of shrub species (2 in both areas) and low shrub densities (6 and 5 stems/hectare, respectively). There were no significant differences between irrigated and non-irrigated areas in terms of shrub species, density, basal area, healthy, dead, or injured stems (Tables 1 and 3).

It appears that the forested areas in the irrigated area are developing an open, park-like overstory that is comprised of less healthy trees than adjacent non-irrigated areas. There seems to be a change in the species composition from the non-irrigated mixed hardwood-pine to red maple-pine-mixed hardwood in the irrigated areas. Overstory density of oak and red maple trees did not appear to be affected by irrigation.

Table 1—Mean[a] overstory (≥11 cm in diameter) number of species per 0.04 ha plot, density, basal area, and stocking for tree, shrub, and total species in irrigated and non-irrigated areas

Species group area	Number of species	Density	Basal area	Stocking
	Per plot	*Stems/ha*	*m^2/ha*	*Percent*
Tree				
Irrigated	4 a	355 b	19 b	73 b
Non-irrigated	5 a	531 a	27 a	100 a
Shrub				
Irrigated	<1 a	6 a	<1 a	-
Non-irrigated	<1 a	5 a	<1 a	-
Total				
Irrigated	5 a	361 b	20 b	73 b
Non-irrigated	5 a	536 a	27 a	100 a

[a] Means with the same letter are not significantly different ($\alpha = 0.05$).

Table 2—Mean density of overstory (≥11 cm in diameter) trees and shrubs by species group[a] in irrigated and non-irrigated areas

Species group	Area: Irrigated	Area: Non-irrigated
	Stems/ha	
Trees		
Ash	11	1
Aspen	23	119
Black cherry	28	56
Hickory	14	1
Oak	74	70
Pine	82	161
Red maple	120	120
Other tree	3	3
Total tree	355	531
Shrubs		
Flowering dogwood	0	1
Sassafras	5	4
Striped maple	1	0
Total shrubs	6	5

[a] Hickory included mockernut and pignut; oak included black, chestnut, scarlet, and white; pine included pitch, Scotch, and eastern white; other tree included American beech, blackgum, slippery elm, and sweet birch (see Appendix 1 for scientific names).

Table 3—Mean[a] overstory (≥11 cm in diameter) tree, shrub, and total healthy, dead, and injured stems in irrigated and non-irrigated areas

Species group area	Healthy	Dead	Injured
		Pct	
Tree			
Irrigated	64 b	7 a	29 a
Non-irrigated	84 a	7 a	9 b
Shrub			
Irrigated	56 a	33 a	11 a
Non-irrigated	0 a	25 a	75 a
Total			
Irrigated	64 b	7 a	29 a
Non-irrigated	83 a	7 a	9 b

[a] Means with the same letter are not significantly different ($\alpha = 0.05$).

Sapling-Sized Stems

A total of 51 sapling-sized tree and shrub species were inventoried, with the irrigated and non-irrigated areas containing 29 and 47 total species, respectively. Number of species per plot (Table 4) was significantly greater in the non-irrigated area (7 species/plot) than in the irrigated area (3 species/plot). Total density also was significantly different between the non-irrigated (2,823 stems/hectare) and irrigated (706 stems/hectare) areas (Table 4).

Of the 21 tree species inventoried, the irrigated area had 13 species, and the non-irrigated area had 19 species. There was a significant difference in number of tree species between irrigated (1 species/plot) and non-irrigated (3 species/plot) areas (Table 4). The 1,585 tree species stems/hectare in the non-irrigated area was significantly greater than the 309 stems/hectare in the irrigated area (Table 4). All tree species, except ash, had substantially lower numbers of sapling-sized stems in the irrigated area as compared to the non-irrigated area (Table 5). There were 118 ash stems/hectare in the irrigated area and 98 stems/hectare in the non-irrigated area. Birch, hickory, oak, and pine sapling-sized stems were present in the non-irrigated area but were nearly absent from the irrigated area (Table 5).

The total number of shrub species was 30. There were 16 and 28 shrub species inventoried in the irrigated and non-irrigated areas, respectively. Numbers of shrub species and shrub densities (Table 4) were significantly greater in the non-irrigated area (3 species/plot and 1,238 stems/hectare) than the irrigated area (1 species/plot and 397 stems/hectare). The non-irrigated area had an abundance of sapling-sized stems for a variety of shrub species, with Tatarian honeysuckle and sassafras being the most prevalent. Hophornbeam, Tatarian honeysuckle, and spicebush were the most common sapling-sized shrub species in the irrigated area. Autumn olive, blackhaw, blueberry, dogwood, privet, and sassafras were less common in the irrigated area than in the non-irrigated area (Table 5).

Table 4—Mean[a] number of species and density of sapling-sized (≥151 cm in height and <11 cm in diameter) tree, shrub, and total species in irrigated and non-irrigated areas

Species group area	Number of species	Density
	0.01/ha	Stems/ha
Tree		
Irrigated	1 b	309 b
Non-irrigated	3 a	1,585 a
Shrub		
Irrigated	1 b	397 b
Non-irrigated	3 a	1,238 a
Total		
Irrigated	3 b	706 b
Non-irrigated	7 a	2,823 a

[a] Means with the same letter are not significantly different ($\alpha = 0.05$).

Table 5—Mean density of sapling-sized (≥151 cm in height and <11 cm in diameter) trees and shrubs by species group[a] in irrigated and non-irrigated areas

	Area	
Species group	Irrigated	Non-irrigated
Trees		
Ash	118	98
Birch	1	24
Black cherry	55	371
Hickory	4	13
Maple	113	850
Oak	7	171
Pine	1	44
Other tree	10	14
Total tree	309	1,585
Shrubs		
Autumn olive	3	56
Raspberry	9	89
Blackhaw	0	23
Blueberry	0	34
Dogwood	1	76
Hophornbeam	11	18
Privet	1	78
Rose	9	101
Sassafras	0	330
Spicebush	14	6
Tatarian honeysuckle	330	386
Other shrubs	19	41
Total shrubs	397	1,238

[a] Birch included paper and sweet; hickory included bitternut, mockernut, and pignut; maple included red and sugar; oak included black, chestnut, northern red, scarlet and white; other tree included American elm, aspen, basswood, black walnut, blackgum, and slippery elm. Dogwood included flowering and gray; other shrub included American chestnut, American hazel, apple, boxelder, buckthorn, common elderberry, cranberry, dwarf oak, hawthorn, Hercules'-club, Japanese barberry, mapleleaf viburnum, musclewood, red elderberry, red mulberry, striped maple, viburnum, and witch-hazel.

Seedling-Sized Stems

Of the 33 seedling-sized tree and shrub species inventoried, only 10 species occurred in the irrigated area, while all 33 species were inventoried in the non-irrigated area. There were significant differences in total species per plot and total density per hectare between the irrigated and non-irrigated areas (Table 6). The irrigated area contained less than 1 species/plot and had a density of 1,127 stems/hectare, whereas the non-irrigated area had 5 species/plot and 107,316 stems/hectare.

The non-irrigated area contained 13 tree species, compared to only 6 species in the irrigated area. On a per plot basis, there were 3 tree species inventoried in the non-irrigated area, versus less than 1 species in the irrigated area (Table 6). Tree density in the irrigated area of 501 seedling-sized stems/hectare was essentially non-existent compared to the 77,970 stems/hectare in the non-irrigated area (Table 6). Seedling-sized stems in the non-irrigated area were dominated by maple, with abundant black cherry and oak (Table 7). Ash, black cherry, and maple were the most abundant species in the irrigated area. However, seedling-sized densities were much lower in the irrigated area for all of the tree species groups, with aspen, paper birch, and eastern white pine not recorded in the irrigated area.

Table 6—Mean[a] number of species and density of seedling-sized (<151 cm in height) tree, shrub, and total in irrigated and non-irrigated areas

Species group area	Number of species	Density
	0.0004/ha	*Stems/ha*
Tree		
Irrigated	<1 b	501 b
Non-irrigated	3 a	77,970 a
Shrub		
Irrigated	<1 b	626 b
Non-irrigated	2 a	29,346 a
Total		
Irrigated	<1 b	1,127 b
Non-irrigated	5 a	107,316 a

[a] Means with the same letter are not significantly different ($\alpha = 0.05$).

Striking differences in the number of shrub species and densities of shrub species stems also occurred between irrigated and non-irrigated areas. Shrub species totaled 20 in the non-irrigated area and 4 in the irrigated area. Both the number of species/plot (2) and stems/hectare (29,346) in the non-irrigated area were significantly greater than the number of species/plot (<1) and stems/hectare (626) in the irrigated area (Table 6). There were 12 seedling-sized shrub species groups in the non-irrigated area, with good densities of blackberry/raspberry, blueberry, rose, sassafras, and Tatarian honeysuckle (Table 7). In the irrigated area, there were only four seedling-sized shrub species groups, and only Tatarian honeysuckle seemed to be somewhat tolerant of the conditions in the irrigated area.

Shrub Coverage

Over all size classes, the non-irrigated area contained 33 shrub species, compared to 20 shrub species in the irrigated area. There was a significant difference in number of shrub species per plot between irrigated (2 species/plot) and non-irrigated (6 species/plot) areas (Table 8). Shrub coverage in the non-irrigated area (61 percent) was significantly greater than in the irrigated area (17 percent) (Table 8). Tatarian honeysuckle had equal coverage values (13 percent, each) on both the irrigated

Table 7—Mean density of seedling-sized (<151 cm in height) trees and shrubs by species group[a] in irrigated and non-irrigated areas

Species group	Area: Irrigated	Area: Non-irrigated
	------------- *Stems/ha* -------------	
Trees		
Ash	94	938
Aspen	0	250
Black cherry	219	21,750
Hickory	31	750
Maple	94	49,781
Oak	63	4,407
Paper birch	0	63
White pine	0	31
Total tree	501	77,970
Shrubs		
Autumn olive	0	563
Raspberry	0	15,531
Blueberry	0	3,406
Common elderberry	0	219
Cranberry	0	188
Dogwood	0	750
Japanese barberry	31	188
Rose	94	2,156
Sassafras	0	1,906
Tatarian honeysuckle	438	3,313
Viburnum	0	688
Other shrubs	63	438
Total shrubs	626	29,346

[a] Hickory included mockernut and pignut; maple included red and sugar; oak included black, chestnut, northern red, and white. Dogwood included flowering and gray; viburnum included mapleleaf and viburnum; other shrub included American chestnut, apple, blackhaw, hawthorn, hophornbeam, spicebush, and striped maple.

and non-irrigated areas, whereas the coverage values of blackberry/raspberry, rose, and sassafras were considerably lower in the irrigated area as compared to the non-irrigated area (Table 8). Coverage values of the other species were too low to evaluate any irrigation effects.

Herbaceous Coverage

Total herbaceous coverage (Table 9) in the irrigated area (80 percent) was much greater than in the non-irrigated area (30 percent), primarily due to a significant difference in broadleaf coverage (63 and 17 percent coverage in irrigated and non-irrigated areas, respectively). Vine and moss coverage values were slightly higher in the irrigated area (15 percent vine and 2 percent moss coverage) than the non-irrigated area (11 percent vine and 1 percent moss coverage). Each area contained less than 1 percent grass coverage.

Table 8—Combined mean coverage of overstory, sapling- and seedling-sized shrubs by species group[a] in irrigated and non-irrigated areas

Species group	Area: Irrigated	Area: Non-irrigated
	------------ % coverage -----------	
Autumn olive	<1	2
Raspberry	1	19
Blueberry	<1	3
Dogwood	<1	3
Hophornbeam	1	<1
Japanese barberry	<1	1
Privet	<1	2
Rose	<1	7
Sassafras	0	9
Spicebush	<1	<1
Tatarian honeysuckle	13	13
Other shrubs	1	2
Total shrubs	17	61

[a] Dogwood included flowering and gray; other shrub included American chestnut, American hazel, apple, blackhaw, boxelder, buckthorn, choke cherry, common elderberry, cranberry, currant/gooseberry, dwarf oak, hawthorn, Hercules'-club, mapleleaf viburnum, musclewood, red elderberry, red mulberry, serviceberry, striped maple, sumac, viburnum, winterberry holly, and witch-hazel.

Table 9—Mean[a] broadleaf, grass, moss, vine, and total herbaceous coverage in irrigated and non-irrigated areas

Species group area	Coverage
	Percent
Broadleaf	
Irrigated	63 a
Non-irrigated	17 b
Grass	
Irrigated	<1 a
Non-irrigated	<1 a
Moss	
Irrigated	2 a
Non-irrigated	1 b
Vine	
Irrigated	15 a
Non-irrigated	11 b
Total	
Irrigated	80 a
Non-irrigated	30 b

[a] Means with the same letter are not significantly different (a = 0.05).

Soils

There were substantial differences between the irrigated and non-irrigated areas in the chemistry of soil A horizon (Table 10). The A horizon of the irrigated area had significantly higher soil pH (7.1), phosphorus (345 kilograms/hectare), magnesium (3.16 milliequivalent/100 grams), and calcium (9.78 milliequivalent/100 grams) than the non-irrigated area (4.8 soil pH, 48 kilograms/hectare phosphorus, 0.39 milliequivalent/100 grams magnesium, and 2.42 milliequivalent/100 grams calcium). The non-irrigated area had significantly higher exchangeable acidity (10.32 milliequivalent/100 grams) than the irrigated area (0.10 milliequivalent/ 100 grams). Potassium (0.19 milliequivalent/100 grams) and cation exchange capacity (13.22 milliequivalent/100 grams) for the irrigated area were not significantly different from the non-irrigated area (0.18 and 13.03 milliequivalent/100 grams potassium and cation exchange capacity, respectively).

For the B horizon (Table 10), the irrigated area had significantly higher soil pH (7.2), phosphorus (295 kilograms/hectare), potassium (0.18 milliequivalent/100 grams), magnesium (0.95 milliequivalent/100 grams), and calcium (2.41 milliequivalent/100 grams) than the non-irrigated area (5.0 soil pH, 45 kilograms/hectare phosphorus, 0.09 milliequivalent/100 grams potassium, 0.18 milliequivalent/100 grams magnesium, and 0.55 milliequivalent/100 grams calcium). The non-irrigated area had significantly higher exchangeable acidity (4.86 milliequivalent /100 grams) and cation exchange capacity (5.61 milliequivalent/100 grams) than the irrigated area (0.00 milliequivalent/100 grams exchangeable acidity and 3.52 milliequivalent/100 grams cation exchange capacity).

Differences between irrigated and non-irrigated areas were a direct reflection of the chemical composition of the wastewater additions, which had greater levels of phosphorus, magnesium and calcium than what would be found in rain water. The soil chemistry in the non-irrigated area was what would be expected for a soil that developed from acid sandstone. With the exception of potassium in the A horizon, soil chemical levels in the irrigated area were what would expected for a soil that developed from a calcareous parent material. Water for the Pennsylvania State University is from wells supplied from primarily limestone bedrock.

CONCLUSIONS

Initial results of the vegetation monitoring program at Pennsylvania State Game Lands 176 indicate substantial differences in species composition and densities of trees and shrubs between the wastewater irrigated and non-irrigated forested areas. Total numbers of combined tree and shrub species in the non-irrigated overstory, sapling-sized, and seedling-sized components were 15, 47, and 33 species, respectively, compared to 17, 29, and 10 species, respectively, for the irrigated components. Overstory, sapling-sized, and seedling-sized stem densities were 536, 2,823, and 107,316 stems/hectare, respectively, for the non-irrigated and 361, 706, and 1,127 stems/hectare, respectively, for the irrigated components. It appears that the forested areas in the irrigated area are developing an open, park-like overstory that is comprised of less healthy trees than adjacent non-irrigated areas. Shrub and herbaceous coverage values were 17 and 80 percent in the irrigated area, compared to 61 and 30 percent in the non-irrigated area. For both A and B soil horizons, the irrigated area had higher pH, higher phosphorus, magnesium, and calcium contents, and lower exchangeable acidity than the non-irrigated area.

Since there were no pre-wastewater irrigation inventories, we can not be certain that the differences after 15 years between the irrigated and non-irrigated areas were due to the application of wastewater. However, the evidence strongly supports that the differences are related to the year-long irrigation with 5 cm of wastewater per week. The reasons for these differences in the plant communities are not known. It is possible that the indigenous herbaceous, shrub, and tree species can not adapt to the enhanced nutrients and water from the irrigation system. There may be other herbaceous, shrub, and tree species that are

Table 10—Mean[a] chemical properties of soil A and B horizons[b] in irrigated and non-irrigated areas

Horizon area	pH	P	Acidity	K	Mg	Ca	CEC
		Kg/ha	------- Exchangeable cations (*meq/100 g*) -------				
Horizon A							
Irrigated	7.1a	345a	0.10b	0.19a	3.16a	9.78a	13.22a
Non-irrigated	4.8b	48b	10.32a	0.18a	0.39b	2.42b	13.03a
Horizon B							
Irrigated	7.2a	295a	0.00b	0.18a	0.95a	2.41a	3.52b
Non-irrigated	5.0b	45b	4.86a	0.09b	0.18b	0.55b	5.61a

[a] Means with the same letter are not significantly different ($\alpha = 0.05$).
[b] A horizon was 0-4 cm below humus layer; B horizon was 10-25 cm below humus layer.

capable of creating and maintaining an acceptable forest community in these amended conditions. It is also possible that the mechanics of the overhead spray of water may be causing physical damage to the plants or creating environments that are favorable for the development of undesirable insects or pathogens. Finally, it is also possible that the bending and breaking on the seedling-sized and sapling-sized stems from heavy ice loading may be selectively removing most of the tree and shrub species from the communities. Based on the data collected in this study, it is clear that modifications to either the plant community species base or the methods of wastewater distribution will be needed to maintain forested ecosystems in the wastewater irrigation area of State Game Lands 176.

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Tree Species

- American beech (*Fagus grandifolia* Ehrhart)
- American elm (*Ulmus americana* L.)
- ash (*Fraxinus* spp.)
- aspen (*Populus* spp.)
- basswood (*Tilia americana* L.)
- bitternut hickory (*Carya cordiformis* (Wangenheim) K. Koch)
- black cherry (*Prunus serotina* Ehrh.)
- black oak (*Quercus velutina* Lam.)
- black walnut (*Juglans nigra* L.)
- blackgum (*Nyssa sylvatica* Marshall)
- chestnut oak (*Quercus prinus* L.)
- eastern white pine (*Pinus strobus* L.)
- mockernut hickory (*Carya tomentosa* (Lam. ex Poir.) Nutt.)
- northern red oak (*Quercus rubra* L.)
- paper birch (*Betula papyrifera* Marshall)
- pignut hickory (*Carya glabra* (P.Mill.) Sweet)
- pitch pine (*Pinus rigida* P.Mill.)
- red maple (*Acer rubrum* L.)
- scarlet oak (*Quercus coccinea* Muenchh.)
- Scotch pine (*Pinus sylvestris* L.)
- slippery elm (*Ulmus rubra* Muhl.)
- sugar maple (*Acer saccharum* Marshall)
- sweet birch (*Betula lenta* L.)
- white oak (*Quercus alba* L.)

Shrub Species

- American chestnut (*Castanea dentata* (Marshall) Borkh.
- American hazel (*Corylus americana* Walt.)
- apple (*Malus* spp.)
- autumn olive (*Elaeagnus umbellata* Thunb.)
- blackberry/raspberry (*Rubus* spp.)
- blackhaw (*Viburnum prunifolium* L.)
- blueberry (*Vaccinium* spp.)
- boxelder (*Acer negundo* L.)
- buckthorn (*Rhamnus cathartica* L.)
- choke cherry (*Prunus virginiana* L.)
- common elderberry (*Sambucus canadensis* L.)
- cranberry (*Viburnum trilobum* Marshall)
- currant/gooseberry (*Ribes* spp.)
- dwarf oak (*Quercus prinoides* Willd.)
- flowering dogwood (*Cornus florida* L.)
- gray dogwood (*Cornus racemosa* Lam.)
- hawthorn (*Crataegus* spp.)
- Hercules'-club (*Aralia spinosa* L.)
- hophornbeam (*Ostrya virginiana* (P.Mill.) K.Koch
- Japanese barberry (*Berberis thunbergii* DC.)
- mapleleaf viburnum (*Viburnum acerifolium* L.)
- musclewood (*Carpinus caroliniana* Walter)
- privet (*Ligustrum obtusifolium* Sieb. & Zucc.)
- red elderberry (*Sambucus pubens* Michx. PFGBW)
- red mulberry (*Morus rubra* L.)
- rose (*Rosa* spp.)
- sassafras (*Sassafras albidum* (Nutt.) Nees)
- serviceberry (*Amelanchier arborea* (Michx.f.) Fern.)
- spicebush (*Lindera benzoin* (L.) Blume)
- striped maple (*Acer pennsylvanicum* L.)
- sumac (*Rhus* spp.)
- Tatarian honeysuckle (*Lonicera tatarica* L.)
- viburnum (*Viburnum dilatatum* L.)
- winterberry holly (*Ilex verticillata* (L.) A.Gray)
- witch-hazel (*Hamamelis virginiana* L.)