2012

Resource Recovery Plan for Eared False Foxglove *Agalinis auriculata* (Michx.) S.F. Blake in Pennsylvania

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Disciplines
Botany

Comments
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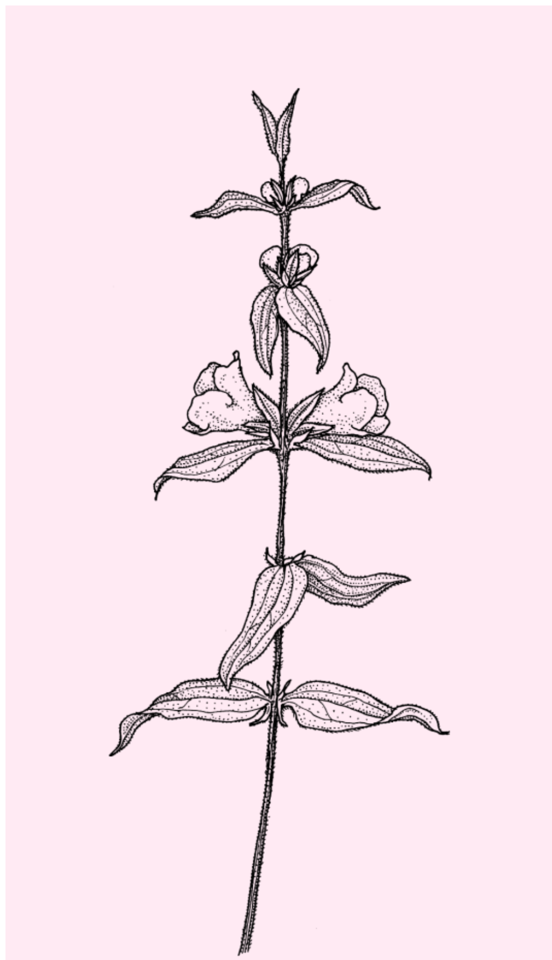

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Cover: *Agalinis auriculata* drawing by Anna Aniśko,
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Agalinis auriculata (Michx.) Blake

Classification

The French botanist, André Michaux, was the first to describe this plant; he collected it in August 1795 in the prairie region of Illinois and named it *Gerardia auriculata* Michx. (Figure 2) (Michaux 1803; Savage and Savage 1986). In 1836 Constantine Rafinesque transferred the species to the genus *Tomanthera* as *Tomanthera auriculata* (Michx.) Raf. (Rafinesque 1836). Bentham renamed the species in 1846 as *Otophylla michauxii* Benth. (Candolle 1846). In 1913, Small, in the Flora of the Southeastern United States, again renamed it as *Otophylla auriculata* (Michx.) Small (Small 1913). The currently accepted name, *Agalinis auriculata* (Michx.) S.F. Blake, dates from a study of specimens in the Clayton Herbarium by Blake in which he transferred the species from *Gerardia* to *Agalinis* (Blake 1918).

Synonyms
Gerardia auriculata Michx. 1803
Tomanthera auriculata (Michx.) Raf. 1836
Otophylla michauxii Benth. 1846
Otophylla auriculata (Michx.) Small 1913
Agalinis auriculata (Michx.) S.F. Blake 1918

Figure 1. Flowering stem of *Agalinis auriculata*

Agalinis is currently placed in Orobanchaceae, a family composed of hemi- and holoparasitic herbaceous plants that contain orobanchin (Stevens 2001). Stomata that do not close are another characteristic of parasitic plants, especially the annual hemiparasites (see Appendix A). Permanently open stomata, which increase the transpiration rate, may have evolved as a mechanism to optimize transfer of water and solutes from host to parasite (Ehleringer and Marshall 1995).

Hemiparasitic plants in Orobanchaceae, which also includes holoparasitic genera such as *Orobanche* and *Epifagus*, were formerly placed in Scrophulariaceae (Stevens 2001). However, recent studies of the plastid gene rps2 by dePamphilis et al. (1997) support a monophyletic origin of holoparasitic members of Orobanchaceae plus hemiparasitic members of Scrophulariaceae *s.l.*, and their segregation in a single family.

The genus *Agalinis* includes 39 species (USDA Plants 2011). In addition to *A. auriculata*, several others are also species of conservation concern (see Appendix B for more information).

Figure 2. Michaux's original description of *Agalinis auriculata* (Michaux 1803). Source: page images from Biodiversity Heritage Library,
http://www.biodiversitylibrary.org/item/108082#page/8/mode/1up

FLORA

BOREALI-AMERICANA,

SISTENS CARACTERES PLANTARUM
quas in America septentrionali collegit et detexit

ANDREAS MICHAUX,
Instituti Gallici Scientiarum, necnon Societatis Agriculturæ Caroliniensis socius.

TABULIS ÆNEIS 51 ORNATA.

TOMUS SECUNDUS.

TYPIS CAROLI CRAPELET.

PARISIIS & ARGENTORATI,
Apud fratres LEVRAULT.

ANNO XI — 1803.

GERARDIA. *L.*

Cal. 5-fidus. *Cor.* bilabiata : labio inferiore 3-partito : lobis emarginatis : medio 2-partito. *Caps.* 2-locularis, dehiscens.

AURICULATA. G. erecta, subsimplex, tota aspera: foliis ovali-lanceolatis, basi 2-auriculatis : floribus uti folia arcte sessilibus, purpureis.

HAB. in pratis regionis Illinoensis.

Description

Morphology

Agalinis auriculata is an annual hemiparasite with a generally unbranched, erect stem to 0.8 m tall (Figure 1). Branching may occur in response to early season damage to the stem apex, such as grazing by deer or rabbits. Leaves are green deeply tinged with purple, lanceolate, with ear-like lobes at the base and opposite on the stem. Leaves and the 4-angled stem are covered with stiff downward pointing hairs making *A. auriculata* scabrous to the touch.

Flowers are showy, pinkish-purple, sessile in upper leaf axils, and about 2 cm long with a corolla tube and five spreading petal lobes (Figure 1). The two upper corolla lobes are slightly smaller and more united than the three lower lobes resulting in overall bilateral symmetry. Dark purple markings are present in the throat of the corolla tube. Filaments are fused to the corolla tube; the lower two are longer than the upper pair. The ovary is bilocular and hypogenous with a single linear style and stigma.

The fruit of *A. auriculata* is a bicarpellate capsule surrounded by a persistent 5-lobed calyx (Figure 3). The capsules remain attached to the stem, but as they dry, the carpels eventually separate releasing seeds. Each capsule contains 50—180 seeds that are 1.3—1.6 mm in length (Cunningham and Parr 1990; Fernald 1950). The outer surface of the seed bears a reticulate covering of large cells derived from the seed coat or testa. The smooth outer wall of each seed coat cell usually collapses or becomes broken as the seed matures, but the persistent radial walls create a honeycomb-like texture on the surface of the seed (Figure 4) (Canne 1980).

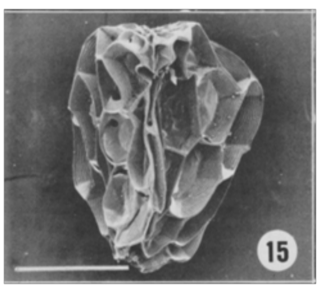


Figure 4. Seed of *Agalinis auriculata*, SEM photo from Canne 1980. Scale bar= 0.5 mm

Figure 3. *Agalinis auriculata* stem with immature fruits

Genetic Diversity

Agalinis auriculata has been found to have a chromosome number of 2*n*=26 (Kondo 1973).

The level of genetic diversity among *Agalinis* species in Illinois was studied by Molano-Flores et al. (2007b) using allozyme and RAPD data. The authors concluded that *A. auriculata* had lower levels of genetic diversity than the more common *A. purpurea* and *A. tenuifolia*, but higher levels than *A. skinneriana*, another rare species.

In a trial of germination rates of seeds from five Illinois populations of *Agalinis auriculata*, the smallest, most remote population had the lowest germination, suggesting inbreeding depression might be a factor (Molano-Flores et al. 2007a). However, the evidence was weak and reflected a limited sampling of the total range of the species.

Reproduction

As an annual, *Agalinis auriculata* must complete its life cycle each year, or rely on multi-year seed viability to bridge a nonproductive season.

Pollination

Mulvaney et al. (2004) observed that individual flowers open in the early morning and remain open for 5—6 hours. The authors report that anther dehiscence occurred first, followed about two hours later by peak receptivity by the stigma. Within 2—3 hours of complete anthesis, the pistil and stamens folded over; the corolla abscised 1—2 hours later.

Pollinators included bees, syrphid flies, soldier beetles, and leaf beetles (Mulvaney et al. 2004). The authors failed to detect floral nectar and concluded that pollen was likely the sole reward for pollinator visits. However, Pennell (1935) suggested that nectar is produced by *A. auriculata* flowers.

Mulvaney et al. (2004) carried out a series of manipulations including bagging flowers while still in bud to exclude pollinators. Treatments of bagged flowers included:

1. non-emasculated and no hand pollination
2. emasculated and no hand pollination
3. emasculated and hand pollinated with self-pollen
4. emasculated and cross-pollinated with pollen from a second population
5. emasculated and cross-pollinated with pollen from an individual at least 12 m away in the same population

In addition the following controls were designated: unbagged and emasculated; unbagged, unaltered. The bags remained on the flowers until October when fruits were harvested and seeds counted.

Mulvaney et al. (2004) found high fruit set in all cases indicating that outcrossing occurs but the flowers are also capable of autogamy (self-pollination). Furthermore, hand pollination with large numbers of pollen grains did not increase seed set, indicating that seed production was not limited by insufficient pollen transfer. Pollen:ovule ratios of 122.6:147.0 in two populations studied (Mulvaney et al. 2004) are consistent with other autogamous species (Cruden 1977).

Seed dispersal

The honeycomb-like surface of *A. auriculata* seed coats may function to make seeds more buoyant in air or water, thus facilitating dispersal. Unlike some members of Orobanchaceae (Stevens 2001), seeds of *Agalinis auriculata* do not appear to have eliasomes (surface oil bodies that attract ants). Seeds are small enough that epizoochory, in which seeds are transported inadvertently by animals by adhering to wet fur or feathers, may be important.

Seed germination requirements and soil-banking potential

Studies of seed germination have produced varying results. Baskin et al. (1991) demonstrated that cold stratification and light are required for seeds of *Agalinis auriculata* to germinate with percent germination increasing with up to 12 weeks of cold treatment. Molano-Flores et al. (2003) achieved maximum rates of germination only after 22 weeks of cold stratification.

Baskin et al. (1991) determined seeds can remain viable in soil for at least four years. Longer trials have not been reported.

Investigators have reported highly divergent germination rates. Low germination (2—5 percent) in greenhouse studies by Cunningham and Parr (1990) was attributed to high daytime temperatures (22—28°C), a range subsequently shown by Baskin et al. (1991) to be inhibitory. Baskin et al. (1991) found seeds germinated best under a temperature regime of 12 hrs at15°C followed by 12 hrs at 6°C.

Molano-Flores et al. (2003) determined that the average rate of seed germination for 5,365 seeds was 3.1 percent. Stratification time varied from 12 weeks to 22 weeks. Seeds stratified for 22 weeks had a 7—8 percent germination rate. Seeds were mixed with sand and spread on the surface of experimental pots containing a 1:2 sand to potting soil mix with no fertilizer added. Light and temperature regimes were not specified.

Molano-Flores et al. (2007a) examined germination rates of seeds of *A. auriculata* collected from five separate populations in Illinois. They found germination rates ranging from 68 to 99 percent under greenhouse conditions.

Ecology

Range

Agalinis auriculata has been reported from 22 states plus the District of Columbia ranging from New Jersey west to Minnesota, south to Texas, and east to South Carolina (NatureServe 2011). Illinois, Iowa, Missouri, Kansas, and Oklahoma have the largest numbers of sites recorded. Dispersal farther east may have been associated with the hypsithermal interval, a post glacial warmer and drier period that occurred from 7,000 to 2,500 years ago (Deevey and Flint 1957). With the return of a cooler, wetter climate, *A. auriculata* may have persisted only on specialized substrates that mimic prairie conditions. Other clusters of prairie plants in the east occur on serpentine barrens, diabase meadows, and limestone barrens.

Habitat

Habitat of *Agalinis auriculata* is described as mesic to dry prairies, fallow fields, borders of upland sterile woods and thickets, marl/calcareous prairies, tallgrass prairies, blackland prairies, prairie-like glades, barrens, and openings (NatureServe 2011). Pennell (1935) lists habitats including moist to dry prairies, old fields, or rarely, open, deciduous woods.

In the Chicago region of Illinois, habitat is described as moist prairie (Swink and Wilhelm 1994). In southwestern Ohio (Adams County, along the Kentucky border) *Agalinis auriculata* populations occur in a prairie glade-woodland complex on seasonally wet, shallow gravelly soils underlain by Peebles dolomite of Silurian age (Knoop 1988). At a site in Virginia it grows in seasonally wet, clay-rich soil derived from diabase geology (VA Dept. Conservation and Recreation 2011). In Missouri *A. auriculata* is found in seasonally wet, sandy loam subjected to periodic inundation (Orzell and Summers 1983). In Mississippi, *A. auriculata* is limited to the blackland prairie region along the border with Alabama (Leidolf and McDaniel 1998).

Seasonally wet prairies on soils with elevated calcium or magnesium levels are the most frequently mentioned habitat. Regular disturbance, which creates patches of bare soil, also appears to be an important factor. There is no evidence for an association of *Agalinis auriculata* with outcrops of serpentinite or serpentine barrens as suggested by Locklear (2011). However, other species in the genus, *A. decemloba, A. paupercula*, and *A. acuta* are known to occur on serpentine barrens in Pennsylvania and/or Maryland.

Host plant relationships

As a hemiparasite, *Agalinis auriculata* has the ability to associate with host plants through haustoria. Greenhouse studies have identified four host plants of *A. auriculata*, all members of Asteraceae: *Helianthus occidentalis, Rudbeckia fulgida* (Cunningham and Parr 1990), *Silphium terebinthinaceum* and *Solidago rigida* (Molano-Flores et al. 2003). Despite a suggestion by Musselman (1972) that *Poa compressa* might be a host, subsequent studies with this species, and other monocots (Table 1), failed to produce evidence of haustoria (Cunningham and Parr 1990, Molano-Flores et al. 2003). Despite a lack of haustoria, the highest rates of seed germination and seedling survival occurred in pots with *Sporobolis heterolepis*; however, the seedlings remained miniaturized, i.e. did not complete their life cycle (Molano-Flores et al. 2003).

It is likely that with more investigation additional host species will be discovered. Other *Agalinis* species have been shown to parasitize members of Poaceae, Juncaceae, Cyperaceae, Caryophyllaceae, Cistaceae, Fabaceae, Fagaceae, Ericaceae, and Violaceae in addition to Asteraceae. Utilization of grasses is also very common with ten grass species documented as hosts for *A. purpurea* (Pennell 1929).

Molano-Flores et al. (2003) succeeded in growing *A. auriculata* to maturity, including fruit production, without a host plant being present. This result is contrary to earlier studies by Cunningham and Parr (1990) and Baskin et al. (1991), who were unable to produce mature plants in the absence of a host. Mann and Musselmann (1981) were able to grow three species of *Agalinis* (*A. aphylla, A. linifolia, A. tenuifolia*) to pre-anthesis in the absence of hosts when soil nutrients were augmented with applications of NPK fertilizer. Plants lacking both fertilizer and potential host plants all died. *Agalinis auriculata* was not part of the study.

Formation of haustorial connections in *Agalinis* can be stimulated by root exudates produced by the host plant (Steffens et al. 1982). Based on work with *A. purpurea*, Baird and Riopel (1984) have suggested that in the absence of a host, *Agalinis* grows autotrophically; but when a host is present, reception of a specific chemical produced by the host's roots triggers the parasitic mode.

Table 1. Evaluation of potential host plants of *Agalinis auriculata*

species	**family**	**fruit prod?**	**reference**
Andropogon gerardii	Poaceae	no	C&P 1990, M-F et al. 2003
Elymus canadensis	Poaceae	no	M-F et al. 2003
Helianthus occidentalis	Asteraceae	yes/no*	C&P 1990, M-F et al. 2003
Liatris squarrosa	Asteraceae	no	C&P 1990
Manfreda virginica	Agavaceae	no	C&P 1990
Parthenium integrifolium	Asteraceae	no	M-F et al. 2003
Physostegia virginiana	Lamiaceae	no	M-F et al. 2003
Poa compressa	Poaceae	no	M-F et al. 2003
Ratibida pinnata	Asteraceae	no	M-F et al. 2003
Rudbeckia fulgida var. *fulgida*	Asteraceae	yes	C&P 1990, M-F et al. 2003
Schizachyrium scoparium	Poaceae	no	C&P 1990
Silphium terebinthinaceum	Asteraceae	yes	M-F et al. 2003
Solidago ptarmicoides	Asteraceae	no	C&P 1990
Solidago rigida	Asteraceae	yes	M-F et al. 2003
Sorghastrum nutans	Poaceae	no	C&P 1990, M-F et al. 2003
Sporobolis heterolepis	Poaceae	no	M-F et al. 2003
Symphyotrichum nove-angliae	Asteraceae	no	M-F et al. 2003
Zizia aurea	Apiaceae	no	M-F et al. 2003

***** Cunningham and Parr (1990) found *Helianthus occidentalis* to be a successful host plant, but Molano-Flores et al. (2003) were not able to repeat that result.

Conservation Status

Due to limited global range and rarity, *Agalinis auriculata* was formerly a category 2 candidate for listing under the Endangered Species Act (USFWS 1990). *Agalinis auriculata* is classified by NatureServe as vulnerable at the global (G3) and national (N3) levels (Figure 4 and Table 2) (NatureServe 2011). *Agalinis auriculata* is not known to occur outside the United States.

Agalinis auriculata has conservation status in each state where it occurs and the District of Columbia (NatureServe 2011). Populations are strongest (S3-vulnerable or S2- imperiled) in Illinois, Iowa, Kansas, Missouri, and Tennessee (Figure 5). *Agalinis auriculata* is classified as (S1) critically imperiled in 13 states and (SX) presumed extirpated or (SH) possibly extirpated in four peripheral states and the District of Columbia (Table 2).

Figure 5. Range and status of *Agalinis auriculata*
Source: NatureServe (2011)

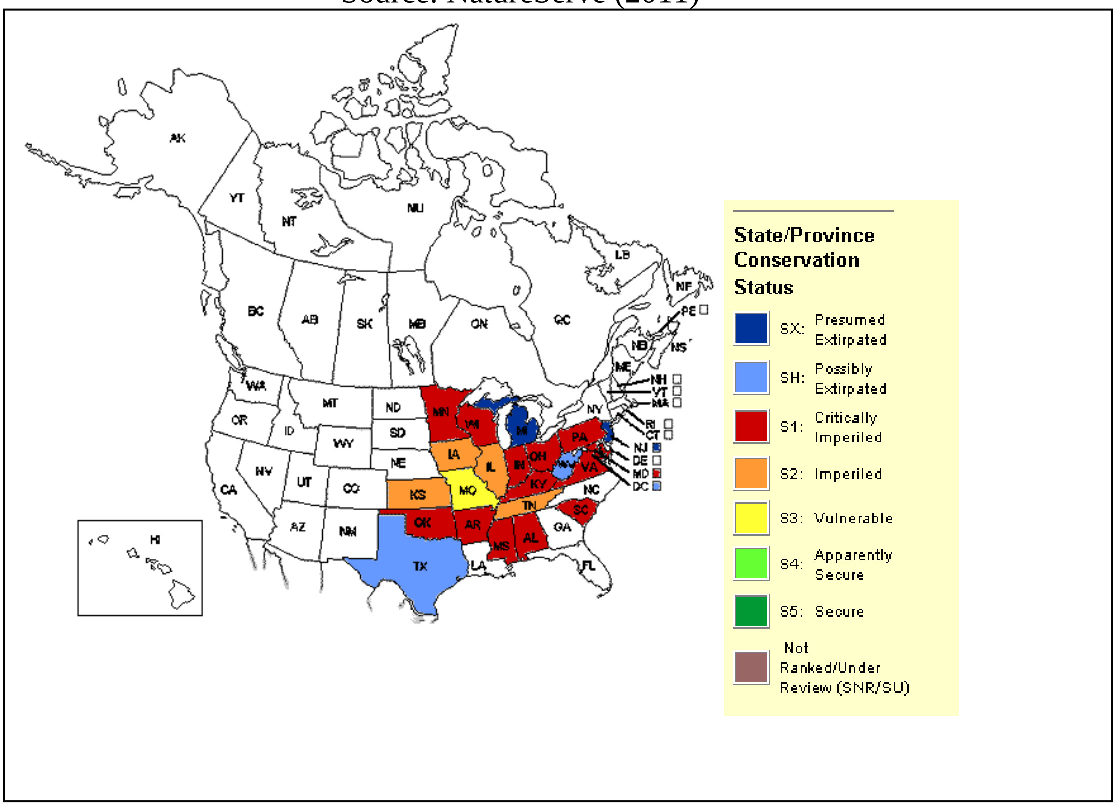


Table 2. State conservation status of *Agalinis auriculata* (Michx.) Blake
Source: NatureServe (2011)

state	***counties with records***	***counties extirpated***		***status***
Alabama	1	0	S1	critically imperiled
Arkansas	2	0	S1	critically imperiled
District of Columbia			SH	possibly extirpated
Illinois	22	9	S2	imperiled
Indiana	4	2	S1	critically imperiled
Iowa	5	0	S2	imperiled
Kansas	19	9	S2	imperiled
Kentucky	1	0	S1	critically imperiled
Maryland	3	1	S1	critically imperiled
Michigan	1	1	SX	presumed extirpated
Minnesota	9	3	S1	critically imperiled
Mississippi	4	1	S1	critically imperiled
Missouri	32	11	S3	vulnerable
New Jersey	1	1	SX	presumed extirpated
Ohio	1	0	S1	critically imperiled
Oklahoma	10	9	S1	critically imperiled
Pennsylvania	7	5	S1	critically imperiled
South Carolina	1	0	S1	critically imperiled
Tennessee	5	1	S2	imperiled
Texas	1	1	SH	possibly extirpated
Virginia	4	3	S1	critically imperiled
West Virginia	1	0	SH	possibly extirpated
Wisconsin	6	4	S1	critically imperiled

Agalinis auriculata in Pennsylvania

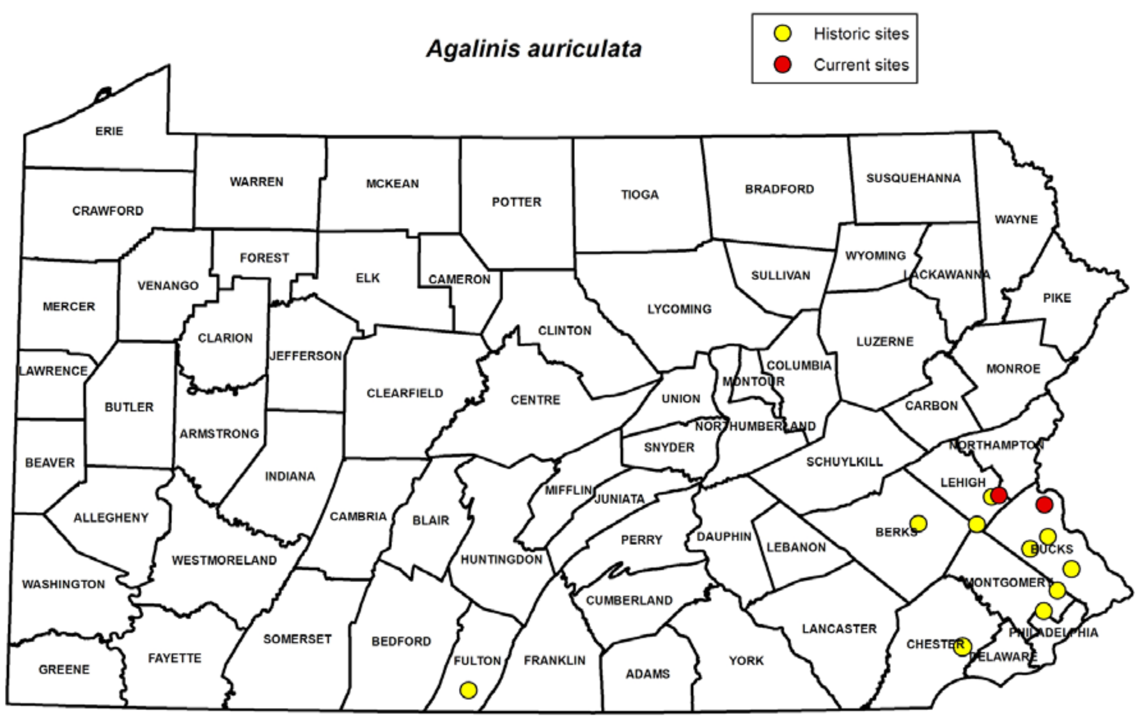
Agalinis auriculata is known from six counties in southeastern and south central Pennsylvania (Figure 6; PA Flora Database 2011).

Early records – The earliest flora of Pennsylvania (Porter 1903) listed *Gerardia (Agalinis) auriculata* in Bucks and Chester Counties. The earliest dated Pennsylvania record is from West Chester in Chester County in 1816 (Darlington 1837). Darlington included the following comment,

> "*This plant, although frequent in the Western country, is extremely rare east of the Alleghany Mountains; and is remarkable for making a transient appearance at long intervals. A single specimen was found here* (referring to West Chester) *in 1816, and it was often fruitlessly sought for, afterwards, until the year 1827; when it was detected in considerable quantity, by Mr. A.H. Derrick, among the stubble of a wheat field, near the brick yards on the southwest side of this borough. A few plants were observed at the same place, the following year; but since then, not a vestige of it has been seen. Mr. Schweinitz informed me that it appeared in a similar manner near Nazareth, Penn. in 1823. I have not heard of it being found elsewhere on this side of the Alleghanies."*
> Darlington 1837, pg. 366.

Whereabouts of the 1816 specimen, if there is one, is not known. Darlington specimens from 1827 and 1828 are at PH.

Figure 6. Historical and current distribution of *Agalinis auriculata* in Pennsylvania
Source: Pennsylvania Flora Database



The earliest Bucks County records are from 1866—1868 (Table 3). A specimen collected by Lewis Sigafoos is undated but the sheet bears the printed label of John and Harvey Ruth, amateur botanists in Bucks County who were active between 1881 and 1918 (White and Rhoads 1996). Benner (1932), in *The Flora of Bucks County*, described the habitat of *Tomanthera* (*Agalinis*) *auriculata* as “old fields” and its frequency as “occasional” citing collections from Revere, Leidytown, Plumstead, Rushland, and Rockhill.

Table 3. Early Pennsylvania collections of *Agalinis auriculata*

county	***year***	***data***	***location***	***collector***	***herbarium***
Berks	1931	8/31/1931	Fleetwood, 1.5 mi SE	Wilkens 1224	PH
Bucks		undated	Revere, near	L. Sigafoos	PH
Bucks	1866	Aug. 1866	Plumsteadville	I.C. Martindale	PH
Bucks	1867	Aug. 1867	Plumstead	J.S. Moyer	PH
Bucks	1868	Aug. 1868	Hilltown	C.D. Fretz	PH
Bucks	1882	Aug. 1882	Hilltown Twp.	C.D. Fretz	PH
Bucks	1925	9/20/1925	Rushland	Geo. Redles	PH
Chester	1827		West Chester	Wm. Darlington	PH
Chester	1828	9/5/1828	West Chester	Wm. Darlington	PH
Chester	1859	Aug. 1859	West Chester	H. Jackson	PH
Chester	1864		West Chester	W. Short	PH
Fulton	1918	9/2/1918	Big Tonoloway Creek near state line “wet meadow”	J. Bright	CM
Lehigh	1910	8/28/1910	Upper Milford Twp. “field 1/3 mile from head of Indian Creek”	H.W. Pretz	PH
Lehigh	1910	9/17/1910	Lanark, 1 mi N “roadside leading south from mountain road”	H.W. Pretz 2960	PH
Lehigh	1948	8/31/1948 flr 10/2/1948 frt	Friedensville zinc mines, mud dam at Hartman shaft	W.H. Witte	PH
Lehigh	1948	8/31/1948 flr 10/2/1948 frt	Friedensville zinc mines, fallow field at the Hartman shafts	W.H. Witte	PH
Lehigh	1948	8/31/1948 flr 10/2 1948 frt	Friedensville zinc mines, mud pond west of the twin pits of the old Hartman zinc mine	W.H. Witte	PH
Montgomery	1909	9/17/1909	Laverock, “meadow just south of PRR station”	B. Long	PH
Montgomery	1910	8/31/1910	Laverock	C.S. Williamson	PH
Montgomery	1913	10/27-28/1913	Laverock, “waste land along PRR”	F.W. Pennell	PH
Montgomery	1914	8/28/1914	Laverock “waste land along PRR”		
Montgomery	1914	9/4/1914	Laverock “waste land along PRR”	F.W. Pennell	PH
Montgomery	1914	9/11/1914	Laverock	W.R. Taylor	PH
Montgomery	1950	9/14/1950	Hatboro “old clay field North Penn Street”	B. Long	CM

The earliest collections of *Agalinis auriculata* from Lehigh and Montgomery Counties were in 1910. Other early collections were from Fulton County in 1918 and Berks County in 1931 (Table 3).

Pennell (1929), while acknowledging the occurrence of *Agalinis auriculata* in Pennsylvania, questioned whether the species was truly native in any of the eastern states, citing the disturbed nature of many of the sites noted by early collectors and the plant's greater abundance in the Midwest. However, a few years later, in his monograph of Scrophulariaceae, Pennell (1935) revisited the question of nativity citing two undated specimens in the British Museum collected by John Clayton, an early Virginia botanist who lived from 1694 to 1773, and labeled by him, "both these I gathered when I went up the Delaware." Benner (1932) agreed with Pennell's initial nativity assessment, stating of A. auriculata, "probably an introduction from the Mississippi Valley".

Current and recent occurrences

Agalinis auriculata is known from a cluster of inactive zinc mines near Friedensville in Lehigh County (Figure 7). An annual census of the two subpopulations at the site has been carried out by John Kunsman of the Pennsylvania Natural Heritage Program since 1987 (Table 4). Since 1993 when the second subpopulation was discovered, the total number of plants has fluctuated between a low of 7 and a high of 258 individuals.

The low population numbers for 2012 may have been caused by a 4.69 inch precipitation deficit for the first 4 months of 2012 (National Weather Service data for Allentown, PA). The resulting lack of soil moisture may have inhibited seed germination or seedling survival.

Agalinis auriculata was first recorded at the Friedensville zinc mines in 1948, at a time when the mines were inactive. The site of a 1910 collection by Pretz from a roadside at Lanark in Lehigh County is approximately 2.5 miles west of Friedensville (Table 3).

Table 4. Annual census data for *Agalinis auriculata* at the Friedensville Zinc Mine Site

year	*subpopulation 1*	*subpopulation 2*	*total*
1987	25	-	25
1988	-	-	-
1989	115	-	115
1990	48	-	48
1991	30	-	30
1992	15	-	15
1993	4	200	204
1994	8	250	258
1995	4	97	101
1996	1	92	93
1997	4	58	62
1998	7	59	66
1999	8	14	22
2000	15	12	27
2001	31	19	50
2002	16	30	46
2003	3	66	69
2004	5	34	39
2005	16	53	69
2006	15	44	59
2007	17	94	111
2008	17	15	32
2009	20	157	177
2010	0	36	36
2011	1	29	30
2012	1	6	7

At Friedensville, *A. auriculata* is growing in what appears to be mine waste consisting mainly of gravel derived from Ordovician dolomite of the Rickenbach Formation. The Lanark site is underlain by shaly limestone of the Jacksonburg Formation (PASDA 2001; Geyer and Wilshusen 1982).

Figure 7. *Agalinis auriculata* habitat at t
photographed 31 Au

Figure 8. *Agalinis auriculata* growing in limestone gravel at the Friedensville Zinc Mine site, photographed 6 October 2011.

Associated species growing at the locations of the two subpopulations at Friedensville include the following: *Ambrosia artemisiifolia, Achillea millefolium, Apocynum cannabinum, Betula populifolia, Celastrus orbiculatus, Daucus carota, Dichanthelium acuminatum, Euphorbia maculata, Fraxinus americana, Juniperus virginiana, Leucanthemum vulgare, Lonicera morrowii, Oxalis stricta, Parthenocissus quinquefolia, Penstemon digitalis, Plantago lanceolata, Pycnanthemum virginiana, Solidago juncea, Solidago nemoralis, Symphyotrichum pilosum* var. *pringlei, Taraxacum officinale, Trichostema dichotomum, Tridens flavus,* and *Viola sagittata*; (A. Rhoads, personal observation, 31 August 2011).

None of the species observed growing at the site of either subpopulation of *A. auriculata* at Friedensville were confirmed host species; however, seven plants in the Aster Family were present.

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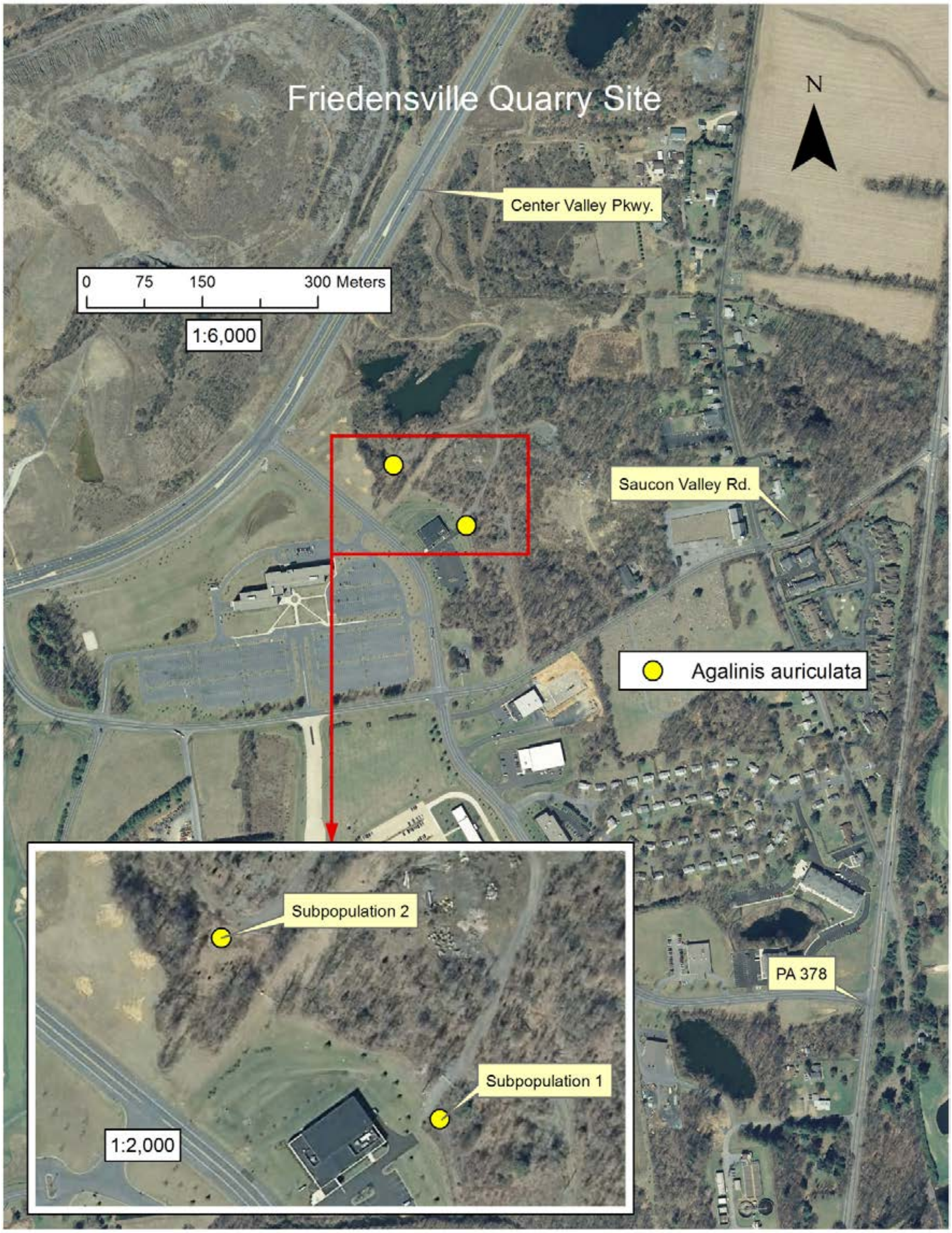
Figure 9. Locations of *Agalinis auriculata* at the Friedensville Zinc Mine site



A site near the village of Revere in Bucks County had *Agalinis auriculata* plants as recently as 2004 (PNHP 2011; J. Kunsman personal communication). The village of Revere is approximately 13 miles southeast of Friedensville. The area is underlain by shale and argillite of the Lockatong Formation, but the recent *A. auriculata* site is part of a superfund site along Rapp Creek which was contaminated by heavy metals in the 1960s and has since undergone several phases of clean-up by the Environmental Protection Agency (EPA 1998, 2002, 2006, 2010).

This population was discovered in 1991 in the area identified in Figure 8 as "South Spray Field" by a consultant working on a remediation plan, and reported to John Kunsman of the Heritage Program. Kunsman has monitored this population since 1991 (Table 5). There is no way of knowing if this population was related to the undated early collection by Sigafoos described only as "near Revere" (Table 2).

Figure 10. Revere Chemical Company site diagram

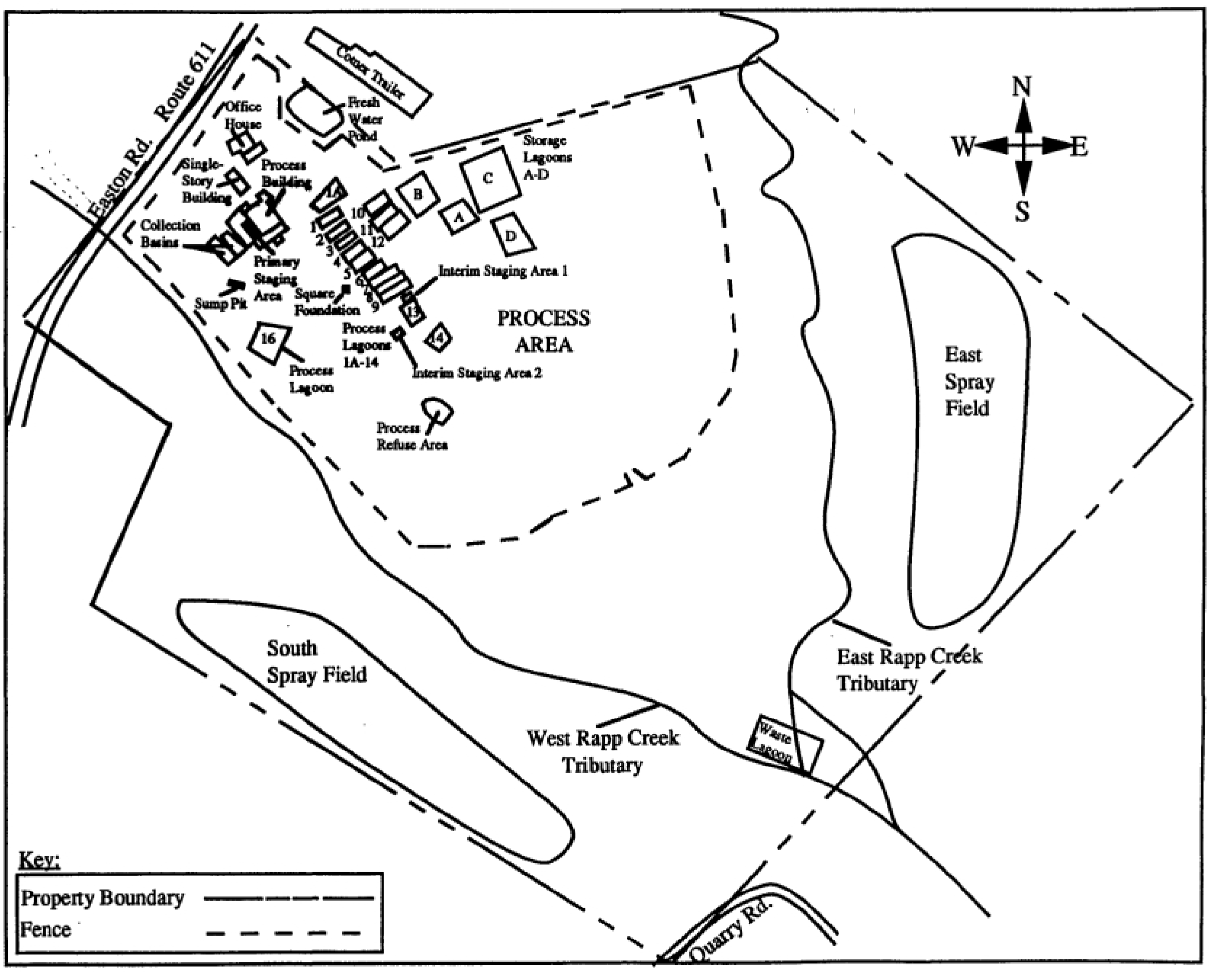


Table 5. Status of *Agalinis auriculata* at Revere Chemical Company site in Bucks County
Source: data from surveys by John Kunsman (PNHP 2011)

date	***number of plants***	***comments***
8/29/1991	95	site a disturbed opening/old field
9/18/1992	29	habitat unchanged
9/7/1993	35	no site visit
8/31/1994	28	getting more difficult to find due to dense vegetation
8/31/1995	61	plants present at sub-populations A-D, widening of orv path may have helped
8/31/1997	36	plants only at only sub-population A, habitat unchanged but vegetation may be denser at sub-populations B-F
9/13/2000	81	no site visit
9/9/2003	13	same spot as 2000
9/2/2004	5	same spot as 2003
10/6/2011	0	vegetation denser due to successional growth

Plant species present in the area where *Agalinis auriculata* was last seen at the Revere Chemical Site included: *Acer rubrum, Agrimonia parviflora, Bidens polylepis, Cornus racemosa, Desmodium paniculatum, Dichanthelium acuminatum, Eupatorium perfoliatum, Euthamia graminifolia Fraxinus americana, Juncus tenuis, Juniperus virginiana, Linum medium* var. *texanum, Lonicera morrowii, Lythrum salicaria, Microstegium vimineum, Onoclea sensibilis, Pycnanthemum tenuifolium, Quercus palustris, Salix discolor, Solidago canadensis, Solidago rugosa, Symphyotrichum lateriflorum, Symphyotrichum nove-angliae, Toxicodendron radicans*; *Ulmus rubra, Vernonia noveboracensis, and Viburnum recognitum* (A. Rhoads, personal observation, 6 October 2011).

More information about the Revere Chemical Company superfund site is in Appendix D.

Status of *Agalinis auriculata* in Other States

Alabama – *Agalinis auriculata* is classified as critically imperiled (S1) (Alabama Natural Heritage Program 2011, NatureServe 2011). It was collected in Pickens County in September 2007 within blackland prairie habitat that extends west into Mississippi (see description below). *Agalinis auriculata* was growing with *Schizachyrium scoparium, Solidago nemoralis, Solidago rigida, Helianthus strumosus*, and *Juniperus virginiana* (Kral et al. 2012; Barone and Hill 2007). Note: *Solidago rigida* is a known host for *A. auriculata* (Molano-Flores et al. 2003). There are also historic records of *A. auriculata* from three other counties, the earliest from 1841 (Alabama Natural Heritage Program 2011).

Arkansas – *Agalinis auriculata* is classified as an inventory element (INV) in Arkansas, indicating it is a species of concern under current review (Arkansas Natural Heritage Commission 2011). *Agalinis auriculata* is known from two counties in Arkansas (NatureServe 2011). At one of those sites, Columbus Prairie, one plant was present in 1998; the following year after a prescribed burn, 50 plants appeared (The Nature Conservancy 2011).

District of Columbia – *Agalinis auriculata* is classified as possibly extirpated (SH) in the District by NatureServe (2011). Hitchcock and Standley (1919) reported it growing in low ground north and east of Washington. *Agalinis auriculata* was collected by E.T. Wherry at Pinehurst, 1 mi ENE of Chevy Chase Circle in the District of Columbia in August 1919. Habitat was described as open woods, in clayey soil, with a subacid reaction (Smithsonian Institution 2011).

Illinois – *Agalinis auriculata* is classified as threatened (LT) in Illinois; with three known occurrences (Illinois Endangered Species Protection Board 2011). Mohlenbrock (1986) stated it occurred in dry prairies and was occasional in the northern three-quarters of the state. Habitat was described as moist black soil prairies, thickets, savannas, abandoned fields, and areas along railroads. Swink and Wilhelm (1994) provided a county level distribution map for the Chicago region showing locations in eight counties in northeastern Illinois. According to Swink and Wilhelm (1994), *A. auriculata* grows in moist prairies with *Andropogon gerardii, Asclepias sullivantii, Comandra umbellata, Elymus canadensis, Euphorbia corollata, Helianthus grosseserratus, Helianthus rigidus, Liatris spicata, Lysimachia quadrifolia, Oxypolis rigidior, Polygala verticillata, Phlox pilosa, Physostegia virginiana, Silphium terebinthinaceum, Solidago nemoralis, Solidago rigida, Symphyotrichum ericoides, S. laeve, Veronicastrum virginicum*, and *Zizia aurea*. Note: *Solidago rigida* and *Silphium terebinthinaceum* have been shown to be hosts for *A. auriculata* (Molano-Flores et al. 2003).

Indiana – *Agalinis auriculata* is classified as threatened (ST) in Indiana. Although a 1991 study concluded that only a single population of *A. auriculata* remained in Indiana (Indiana Division of Nature Preserves 1991), between 1991 and 2010 ten extant sites were found in Lake County in the Chicago Lake Plain physiographic region. Population sizes ranged from three to more than 100 individuals. Sites were described as mesic or wet prairie; several locations were along railroad tracks. Associated species included *Agalinis tenuifolia, Coreopsis tripteris, Eryngium yuccifolium, Eupatorium serotinum, Lysimachia quadrifolia, Populus tremuloides, Pycnanthemum virginiana, Silphium terebinthinaceum, Solidago altissima, and Sorghastrum* *nutans* (Indiana Department of Natural Resources, 2011). Note: *Silphium terebinthinaceum* has been confirmed as a host for *A. auriculata* (Molano-Flores et al. 2003).

Iowa – Records of *Agalinis auriculata* in Iowa go back to 1883 and document its occurrence in 47 of Iowa's 97 counties. State status is special concern (SC) denoting problems suspected, but not yet documented. This ranking does not confer special protection (Iowa Department of Natural Resources 2011a). Since 1986, surveys have confirmed 48 extant populations in 30 counties. The greatest concentration of sites is in the southern one-third of the state. Population size varies from "several plants" to 1,500 or greater. Habitat is described primarily as disturbed moist prairie, but clay barrens, reconstructed tallgrass prairie, and sedge meadow are also mentioned (Iowa Department of Natural Resources, 2011b). A survey of 20 roadside vegetation remnants in Johnson County revealed that *Agalinis auriculata* was present at only one site (Watson 2007).

Kansas – *Agalinis auriculata* is not assigned an official state status in Kansas (Kansas Natural Heritage Inventory 2011a); however, it is ranked imperiled (S2) in the state by NatureServe (NatureServe 2011). The Kansas Biological Survey (Kansas Natural Heritage Inventory 2011b) lists 20 sites for *Agalinis auriculata* in 16 counties; eight are ranked extirpated or historical. Of the remaining12, two sites are ranked excellent, two are good, and one is poor; seven sites were confirmed extant, but the viability was not assessed. Habitat was described as mesic tallgrass prairie including some eroded, grazed, or brushy sites, and oak-hickory woodlands. Substrates were usually sandstone-derived, but also included clayey soils over shale or limestone. Population sizes fluctuate widely from year to year and new populations continue to be encountered (C. Freeman, Kansas Biological Survey, personal communication, 9 November 2011).

Kentucky – *Agalinis auriculata* has endangered status in Kentucky where a single population is known. It is described as occurring in barrens and prairie habitat. (Kentucky Nature Preserves Commission 2011)

Maryland – *Agalinis auriculata* is classified as endangered in Maryland (Maryland Department of Natural Resources 2010). *Agalinis auriculata* was described as rare in open woods or dry to moist fields by Brown and Brown (1984). Three populations are known, one is considered historical, last seen in 1950 (Norden et al. 1984). In 1999 a site on the floodplain of the Potomac River in Frederick County contained three plants, down from approximately 100 fruiting plants in 1993. The third site, located in Prince Georges County, was last surveyed in 1995 when it had 37 flowering and fruiting plants (P. Stango, personal communication, 7 November 2011).

Michigan – *Agalinis auriculata* is classified as extirpated in Michigan (Michigan Natural Features Inventory 2011). It was collected in 1837 and 1838 in sites described as bur oak opening in St. Joseph County and dry openings in Cass County (Voss 1996). Both counties are in southwestern Michigan along the Indiana state line.

Minnesota – *Agalinis auriculata* is classified as endangered in Minnesota. It is known from prairie remnants in seven or eight counties in southern Minnesota. Early records were from wet meadows in the Minnesota River valley, but more recent sites are primarily prairie remnants persisting along railroad rights-of-way. Populations are small, mostly less than 50 plants. (Minnesota DNR 2011).

Mississippi – *Agalinis auriculata* is classified as critically imperiled (S1) in Mississippi by NatureServe (2011); however, the state endangered species program only lists plants that are included in the Federal Endangered Species list (Mississippi Natural Heritage Program 2011) so *A. auriculata* has no official state status. *Agalinis auriculata* occurs in open prairie habitat of the blackland prairie region of Mississippi (Mississippi Entomological Museum 2011). Blackland prairies are described as having highly organic black soil overlying Cretaceous chalk or marl (Leidolf and McDaniel 1998). Seven *A. auriculata* plants were observed at Sixteen Section Prairie in 1994 in an area of open prairie dominated by *Andropogon glomeratus, A. virginicus, Bouteloua curtipendula, Schizachyrium scoparium*, and *Panicum virgatum* (Leidolf and McDaniel 1998). Most of the former open prairie habitat in Mississippi has been converted to agricultural uses, what remains is threatened by fragmentation and accelerated invasion by exotic species Leidolf and McDaniel 1998). *Agalinis auriculata* was not found in a survey of the herbaceous flora of 19 blackland prairie remnants in Mississippi and Alabama carried out in 2005—06 (Barone and Hill 2007).

Missouri – *Agalinis auriculata* does not have official state status (Missouri Department of Conservation 2011); however, it is ranked S3 (vulnerable) in Missouri by NatureServe (2011). As of 1983, the only known extant population of *A. auriculata* in Missouri occurred in an old field on a creek floodplain, in sandy loam soil that is seasonally wet and periodically inundated. At this location, *A. auriculata* was frequently observed colonizing soil mounds created by the plains pocket gopher. First observed in 1971, the population has ranged from 4—35 plants (Orzell and Summers 1983). The presence of non-native invaders including *Dipsacus laciniatus, Lonicera japonica*, and *Rosa multiflora* was noted. *Agalinis auriculata* is currently reported from 13 counties on habitats described as prairies, old field, old road beds, and forest edges; often in dry areas that are open due to disturbance such as erosion or grazing. Historical records occurred in five additional counties (Smith 2000).

New Jersey – *Agalinis auriculata* does not have an official state status in New Jersey (New Jersey Division of Parks and Forestry 2011). It is known from a single early record from Middlesex County (Hough 1983) and is classified as SX (presumed extirpated) in New Jersey by NatureServe (2011).

Ohio – *Agalinis auriculata* is classified as endangered (E) in Ohio (Ohio Department of Natural Resources 2011). Historically *A. auriculata* was known from four counties; however, records from three of the counties are pre-1980 (Knoop 1988). A fourth site, in Adams County on the Kentucky border, was discovered in 1985 when 200 plants were found scattered throughout a 40 ha prairie glade-woodland. The following year, 600 plants were tallied. The Adams county site is seasonally wet prairie underlain by Peebles dolomite. The soil, which is very stony has a black, fine-grained, light, porous matrix with high water-holding capacity (ph 7.5—8.1). It supports a grassland community dominated by *Andropogon gerardii*, *Bouteloua curtipendula, Schizachyrium scoparium,* and *Sorghastrum nutans* (Knopp 1988). This site was revisited in 1992, 1999, 2005, and 2010; the highest count was over 2,000 plants following a prescribed burn (R. Gardner, personal communication, 9 November 2011). In 2010 an additional site with over

100 plants was discovered in Greene County in habitat described as "thin soils over limestone in an abandoned stone quarry" (Ohio Biodiversity Database 2011).

Oklahoma – *Agalinis auriculata* has no official status in Oklahoma, but it is tracked by the State Heritage Program (Oklahoma Natural Heritage Program 2011). *Agalinis auriculata* is ranked S1 (critically imperiled) in Oklahoma by NatureServe (2011). Historically *A. auriculata* is known from three sites; however two of those populations are extirpated. The sole extant site occurs in Choctaw County, and is described as prairie hay meadows bordered by upland woods. Factors threatening the continued existence of *A. auriculata* in Oklahoma include conversion of native prairie to cropland, planting of exotic grasses in pastures, and mowing of hayfields before seed set and dispersal (Oklahoma Natural Heritage Program 2011).

South Carolina – *Agalinis auriculata* is classified as a species of concern (SC) by the South Carolina Department of Natural Resources (2011a). It is known from a single site in York County and was most recently documented in 1987 when it was described as infrequent, scattered with *Andropogon*, *Aster,* and *Silphium* at the edge of a powerline right-of-way (South Carolina Department of Natural Resources 2011b).

Tennessee – *Agalinis auriculata* is classified as endangered in Tennessee and is recorded as occurring in four of the state's physiographic regions: Western Highlands Rim, Ridge and Valley, Cumberland Plateau, and Sequatchie Valley (Tennessee Natural Heritage Program 2008). Habitat of *A. auriculata* is described as calcareous barrens with gravelly, shallow soil that is wet in winter and very droughty in summer (Cunningham and Parr 1990).

Texas – *Agalinis auriculata* is not currently listed in Texas, but was previously ranked as historic. It was dropped after review in 2004. *Agalinis auriculata* is known from one late 19th century specimen labeled "Benbrook" (Texas Parks and Wildlife Department 2011). It is ranked as SH (possibly extirpated) in the state by NatureServe (2011). Correll and Johnston (1970) listed the habitat of *A. auriculata* as prairies, open woods, and fields in north-central Texas.

Virginia – *Agalinis auriculata* is not listed by the Virginia Division of Natural Heritage; however it is classified as critically imperiled (S1) in Virginia by NatureServe (2011). Of the seven *A. auriculata* sites documented, six are ranked as historical (not seen in 25 years or more). The most recent sighting of the species dates from 1993, when 400 plants were found growing along a dirt road in the vicinity of several junked automobiles. The soil, which is derived from diabase geology, was described as seasonally wet and clay-rich. An attempt to relocate *A. auriculata* at the site in 2005 was unsuccessful. Habitat destruction caused by road widening and successional growth of juniper and pine may have caused the loss of this population (Virginia Department of Conservation and Recreation, Division of Natural Heritage 2011).

West Virginia – *Agalinis auriculata* is classified as historical (West Virginia Natural Heritage Program 2007). It was known from moist open fields at a single site in Morgan County (Strausbaugh and Core 1977).

Wisconsin – *Agalinis auriculata* is classified as special concern (SC) in Wisconsin. It occurs in six counties in the southern part of the state where it is found in prairies and open upland woods.

Associated species include *Calamagrostis canadensis, Euthamia* sp., and *Solidago ohioensis* (Wisconsin Department of Natural Resources 2011)**.** Two previously unknown populations were found in southeastern Wisconsin in 1999. A mesic prairie contained approximately 600 plants. Associated species included *Cornus racemosa, Pycnanthemum virginianum,* and *Solidago graminifolia;* a site containing low prairie and old field supported 120—160 plants growing with *Cornus racemosa, Helianthus* sp., *Oxypolis rigidior, Pycnanthemum virginianum, Solidago graminifolia, and Solidago rigida* (Leitner 2001). Note: *Solidago rigida* has been shown to serve as a host plant for *Agalinis auriculata* (Molano-Flores et al. 2003).

Critical Management Issues

Habitat Loss

The prairie habitats of Agalinis auriculata are among the most endangered ecosystems in North America (Noss and Peters 1995). Conversion of prairies to agriculture and other cultural uses, and suppression of wild fires threaten A. auriculata. Following disturbance, remaining habitat is often fragmented and vulnerable to invasion by non-native, invasive species.

Successional growth of woody plants has apparently limited availability of suitable habitat in Virginia (Virginia Dept. Conservation and Recreation 2011), Pennsylvania (J. Kunsman personal communication), Kansas (Ward 1995), Missouri (Orzell and Summers 1983; Rizzo 2003), and Illinois (Vitt et al. 2009).

Role of Disturbance

Disturbance appears to be an important factor in creating and maintaining habitat for Agalinis auriculata. Historically, intact prairie ecosystems were subject to periodic fire and disturbance caused by grazing elk and bison, which in turn provided bare areas suitable for A. auriculata establishment. The excavations of smaller mammals, including the pocket gopher, have also been observed to contribute to the creation of suitable seed beds (Orzell and Summers 1983).

Ward (1995) reported plots of naturally occurring Agalinis auriculata manipulated via mowing and tilling followed by hand-seeding had significantly higher seedling emergence than naturally occurring plots not seeded or disturbed. Seedling emergence was greater in the second year, and un-manipulated plots dominated by Solidago canadensis produced few seedlings. Prescribed burning has resulted in dramatic increases in populations of A. auriculata at numerous sites including Columbus Blackland Prairie in Arkansas (The Nature Conservancy 2011) and Adams County, Ohio (R. Gardner, personal communication 9 November 2011).

Disturbance caused by glaciation may have favored the establishment of Agalinis auriculata in the northern part of its range. Pennell (1935) pointed out that A. auriculata had "extensively reoccupied glaciated territory, so that most of the species range lies north of the southern limit of glaciation."

Succession

Successional growth of woody plants is mentioned as a probable factor in population declines in Virginia (Virginia Dept. Conservation and Recreation 2011), Pennsylvania (J. Kunsman personal communication), Kansas (Ward 1995), Missouri (Orzell and Summers 1983; Rizzo 2003), and Illinois (Vitt et al. 2009).

Herbivory

Deer – Vitt et al. (2009) studied deer browsing of *Agalinis auriculata* at five sites in northern Illinois. An initial census revealed 40 percent of plants were being browsed resulting in a reduction in the number of fruits. The authors modeled the effects of herbivory and brush removal on fecundity and concluded that *A. auriculata* will not persist at this site without frequent brush removal and reduction in browsing to a level that does not exceed 35 percent of the adult plants. Damage to *A. auriculata* by deer was also reported by Molano-Flores et al. (2007a) and Mulvaney et al. (2004), but not quantified.

Despite the widespread incidence of severe impact on herbaceous plants by white-tailed deer in Pennsylvania (Latham et al. 2005), there is little evidence, other than the occasional nipped off stem, that deer browse is a major threat to Pennsylvania populations of *Agalinis auriculata* (J. Kunsman, personal communication).

***Insects* –** Mulvaney et al. (2006) studied the impact of herbivorous insects on Agalinis auriculata at two sites in Illinois. The authors identified nine species whose feeding targets included flowers, leaves, pollen, and/or seeds. Levels of herbivory were generally low except larvae of a moth (*Endothenia hebesana*), which damaged 6—89 percent of fruits over a three year period 1999 to 2001. The percentage of damaged seeds in herbivore-infested fruits ranged from 0—100 percent in 2001, the only year for which data were available (Mulvaney et al. 2006). Note: An exit hole and associated frass were observed in an *A. auriculata* fruit at Friedensville in 2011 (A. Rhoads, personal observation).

Invasive Species

Non-native invasive species may threaten survival of *Agalinis auriculata*; at the Revere Chemical Company site in Bucks County, Pennsylvania, Japanese stilt grass (*Microstegium vimineum*) has invaded the area where *A. auriculata* occurred as recently as 2004. At the Friedensville Zinc Mine site, invasion by *Celastrus orbiculatus* and *Lonicera morrowii* threatens *A. auriculata* (J. Kunsman, personal communication).

Loss of Genetic Diversity

Agalinis auriculata may be vulnerable to inbreeding depression resulting from loss of genetic diversity. Populations of more than a few hundred plants are rare and at many sites the number is much lower. Molano-Flores et al. (2007a) examined germination rates of seeds of *Agalinis auriculata* collected from five separate populations in Illinois. Germination rates were lower in seeds from the smaller, more isolated populations, which they interpreted as evidence of inbreeding depression. However this study must be considered preliminary as the area sampled was only a small portion of the total range of the species and the differences were not great.

Conclusions

Agalinis auriculata is an early successional herbaceous annual dependent on periodic disturbance to produce a suitable seed bed. Ideal habitats include prairies or old fields that are wet early in the season and contain patches of bare soil.

As an annual hemi- or holoparasite, *A. auriculata* must regenerate from seed every year and find an appropriate host plant. Little is known about the spectrum of host plants suitable for *A. auriculata*; haustorial connections have been documented with only four species, all in Asteraceae. None of these species have been reported at the single extant location of *A. auriculata* in Pennsylvania or at a second site where the species was known as recently as 2003 (A. Rhoads, personal observation, 2011). It is not known whether *A. auriculata* can complete its life cycle in a natural setting without forming haustorial connections to a host plant, although this has been demonstrated under experimental greenhouse conditions.

Variations in population size that vary by a factor of 10 or more from year to year have been observed for *Agalinis auriculata.* This is not unusual for an annual; in the case of *A. auriculata*, large populations typically appear immediately following prescribed burning. *Agalinis auriculata* populations typically do not persist at a site for extended periods of time in the absence of active management because of succession by woody plants.

New populations of *Agalinis auriculata* surface periodically, especially in the prairie states, but also in Pennsylvania (Darlington 1837). It is not known whether they represent previously un-noticed populations that have suddenly expanded as *A. auriculata* can be quite cryptic when present in small numbers. If they are new populations, how they become established is not known. Seed dispersal has not been studied and little is known about seed bank viability other than that seeds can remain viable in soil for up to four years.

Recommendations

Stabilization of Existing or Recent Populations
Population monitoring and efforts to retard succession have been carried out at the Friedensville site the past 24 years (J. Kunsman, personal communication). This activity should be continued. In addition, other areas of suitable habitat for *Agalinis auriculata* should be sought within the zinc mine complex at Friedensville.

An effort to restore early successional conditions should be undertaken at the Revere Chemical south spray field site through removal of *Acer rubrum* and *Juniperus virginiana* plus mowing. The most recent sighting of *Agalinis auriculata* at the Revere site was along a mowed path that enters the site from an adjoining property (PNHP 2011; J. Kunsman, personal communication). In addition, the fenced "process area" (EPA 2010) may contain other suitable habitat for *A. auriculata*. These areas should be evaluated and seeded if found to be suitable. Small quantities of seed could be obtained from the Friedensville population.

The Revere Chemical site is now owned by Nockamixon Township, the local municipality; the intent is to develop part of it as a park (Nockamixon Township 2011).

Seed from one or more out-of-state locations should be sought in the interest of increasing genetic diversity of the Pennsylvania population of *Agalinis auriculata*.

Establishment of New Populations
Suitable habitat should be sought for the establishment of new populations of *Agalinis auriculata*, perhaps in utility rights-of-way where woody plant invasion is controlled by active management.

Measures of Success

- Stabilization of the Friedensville population.
- Re-establishment of the Revere Chemical Company population.
- Establishment of *Agalinis auriculata* at 2—3 additional sites.

Research Needs
More specific recommendations for recovery might be possible if more was known about the following aspects of the life history of *Agalinis auriculata*:

- seed dispersal
- seed bank viability
- range of suitable host plants

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Appendix A. Notes on the Biology of Hemiparasitic Plants

Haustoria connections – *Agalinis auriculata* is a root hemiparasite, it attaches to its host plant by means of haustoria, modified roots that contain modified xylem. After penetrating the endodermis, haustorial tip cells enter host xylem vessels through side wall pits. They then enlarge and appear to adhere to the wall of the invaded vessel, quickly establishing xylem transmission. Available evidence indicates that functional phloem connections are not established (Riopel and Timko 1995).

Studies of the role of haustorial-inducing factors (HIFs) of host origin have produced variable results. They are clearly involved in some interactions between members of the Orobanchaceae and their host plants, including some species of *Agalinis*, but not in others (Riopel and Timko 1995). Data on the involvement of HIFs in parasitism by *Agalinis auriculata* are not available.

Transpiration in parasites – An interesting aspect of the relationship between parasites and their host plants is the difference in transpiration rates. Transpiration rates in hemiparasitic root parasites exceed those of the host by several fold. Although host stomata typically close at night, those of the parasites often remain open. Although this may result in a reduction in water use efficiency, it maximizes heterotrophic carbon gain. The higher the transpiration rate the greater the movement of organic and nitrogen–containing compounds from the host into the parasite. Annual root parasites, which complete their life cycle in a single season show no evidence of stomatal closure. Perennial root parasites, on the other hand, show at least partial stomatal closure at night (Ehleringer and Marshall 1995).

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Appendix B. Status of Other *Agalinis* Species

There are 39 species of *Agalinis* in the United States (USDA 2011). Most are herbaceous, hemiparasitic annuals; although the genus also includes a few species that are perennials. Six species are native to Pennsylvania (Rhoads and Block 2007): an additional six species occur in the northeastern United States and adjacent Canada (Gleason and Cronquist 1991). One species, *A. acuta*, is listed as endangered under the Federal Endangered Species Act (USFWS 2011). *A. skinneriana* is ranked G1 (globally critically imperiled) (NatureServe 2011). Three species are ranked by the Pennsylvania Natural Heritage Program: *Agalinis decemloba* is classified PX (extirpated in the state), *A. auriculata* and *A. paupercula* are both listed as PE (endangered in PA) (PNHP 2011).

Agalinis auriculata shares many life history characteristics with the federally endangered *A. acuta* Pennell. Both are annuals of grassland habitats which are disturbance dependent, and show large year to year fluctuations in population size.

Agalinis acuta has a more limited range, it occurs in New York, Massachusetts, Connecticut, Rhode Island, Delaware, Maryland. Its habitat includes grasslands communities dominated by one or more of three grasses: little bluestem (*Schizachyrium scoparium*), Virginia broomgrass (*Andropogon virginicus*), or Indian grass (*Sorghastrum nutans*). Soils are nutrient-poor, usually acidic, and excessively drained. The more northerly Coastal Plain populations inhabit open sandy areas on moraines and sandplains, or glaciolacustrine terraces. The disjunct *A. acuta* population in Maryland occupies a nutrient-poor, circumneutral serpentine barren (Farnsworth 2010). An underlying factor common to all sites supporting *A. acuta* is the lack of competition from other species - a factor imposed by conditions that include extremely nutrient-poor, and sometimes minerally toxic, soils and regular or sporadic disturbance (USFWS 1989; Farnsworth 2010).

Agalinis auriculata sites are typically on highly organic (blackland) prairie soils underlain by dolomite or limestone, that are seasonally wet. Despite these differences, both species are declining for reasons stated as: loss or degradation of habitat brought about by development, altered disturbance regimes, and woody plant succession (USFWS 1989, USDA 2011). The generally small population sizes of both species also make them vulnerable to stochastic events and biological phenomena such as inbreeding depression which can limit future adaptability.

Agalinis skinneriana, a globally imperiled (G1) species of Midwestern prairies and glades, occurs from Ontario and Michigan south to Oklahoma, Louisiana, and Alabama plus a single site in Maryland. It, too, is a disturbance dependent annual, with most populations less than 50 plants. Reasons for decline of *A. skinneriana* are given as: habitat loss, habitat degradation, and suppression of natural disturbance regimes (Teitmeyer 2010).

Agalinis decemloba, with a range extending from Pennsylvania south to Florida and Louisiana, is believed to be extirpated in Pennsylvania. .*Agalinis paupercula* is a Pennsylvania endangered species of open sandy ground and pond shores. Its range extends from Manitoba, Ontario, Quebec, and Nova Scotia south to Illinois and Virginia (PNHP 2011; USDA Plants 2011).

Agalinis purpurea G5, NR (S3 in NY and WV) and *Agalinis tenuifolia* G5, NR (S5 in NY and WV) are annual hemiparasites of moist sandy soils of pinelands and barrens. *Agalinia purpurea* and *A. tenuifolia* have large ranges, extending from eastern Canada to the Gulf States.

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Appendix C. Brief History of the Friedensville Zinc Mine Site

Zinc was discovered at the Ueberroth farm north of Friedensville, Lehigh County in the early 1800s but it wasn't until a process for producing zinc oxide was developed in 1853 that mining began in earnest. In 1855 the Pennsylvania and Lehigh Zinc Company (later Lehigh Zinc Company) was formed to mine and process the ore. Several open pit mines were operated continuously until 1876. However, problems with flooding in the mines caused all operations to cease by 1893.

The New Jersey Zinc Company acquired the Friedensville mines starting in 1899 and after exploration of the remaining resources, decided to reactivate the site by establishing an underground mine. A shaft 1,261 feet deep was sunk between 1945 and 1952. Between the time production resumed in 1958 and 1973, 7.5 million tons of ore were removed

At the surface the ore was crushed to 1.25 inch size, concentrated by flotation, and then hauled by truck to the New Jersey Zinc Company smelter at Palmerton, PA, a distance of 28 miles. Non-ore residue was discarded as tailings, used as mine backfill, or diverted to a limestone processing area where it was prepared for sale as dolmitic limestone for industrial and agricultural uses (Metsger et al. 1973).

The mine closed in 1983 and flooded as soon as operations, which included constant pumping, ceased. The land was subsequently bought by the Stabler Land Company and developed as an industrial park (Sharp 1984).

The presence of *Agalinis auriculata* at the site was first detected in 1948 between the early open pit mining and the later underground activity. Following acquisition of the site by the Stabler Land Company, Heritage Program Botanists re-confirmed its presence in 1987. The areas where *Agalinis auriculata* occurs were fenced and marked and protected from development. The two extant sub-populations of *Agalinis auriculata* are growing in open areas with sparse vegetation and gravelly soil.

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Appendix D. Brief History of the Revere Chemical Company Superfund Site

The Revere Chemical Company, which occupied a 113-acre site located on Route 611 in Nockamixon Township, Bucks County, PA, was an acid waste, metal, and plating waste reclamation facility that was in operation from 1963 to 1969. It was closed by a court order in 1969 when it was discovered that it had contaminated the two tributaries of Rapp Creek that flow through the site.

The company abandoned the site in early 1970 leaving full and empty drums, waste-filled lagoons, and piles of solid waste. The Pennsylvania Department of Health conducted sampling and concluded that the wastes included chromic acid, copper sulfate, other heavy metals, sulfuric acid and ammonia. During 1970-1971, 3.5 million gallons of liquid waste were removed and remaining sludge was stabilized with lime, sodium sulfide, and sodium sulfite and buried on site.

In 1984 the Environmental Protection Agency removed 22 drums of waste chromic acid and 30 cubic yards of sludge containing copper and chromium. The site was added to the National Priorities List (superfund) in July 1987. Starting in 1991, 500 crushed drums or drum fragments and associated contaminated soil were removed. Extensive contamination of soil and groundwater was documented and a decision was made in 1993 to cap the most severely affected area to prevent further leaching. In addition the capped area was fenced, drainage swales were constructed to carry surface water away from the capped area, and monitoring wells were installed (EPA 1991, 1998, 2002, 2006, 2010).

While most of the activity of the Revere Chemical Company took place within the 25-acre "process area" that was capped and fenced during the clean-up, two smaller areas, designated as "east spray field" and "south spray field" are also located on the property (Figure 1 in EPA 1991). These sites were used for disposal of liquids during the metals reclamation operations (EPA 2006). In 1991 a consultant conducting a site inventory discovered a population of the endangered plant, *Agalinis auriculata*, in the south spray field (EPA 2006). No remediation activities were carried out on the southern side of the property (EPA 2006).

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