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REMEDIATION OF AN INDIANA BROWNFIELD: A STUDENT IMMERSIVE LEARNING EXPERIENCE

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ABSTRACT. Over five years a former auto salvage yard in Indiana was transformed from an unsightly and hazardous brownfield to an urban green space by student teams from Ball State University, Muncie, IN. The project assessed the feasibility of selected turf species for recolonization of barren and potentially toxic soil. This was followed by a phased design and implementation plan for the space, providing different stages of rehabilitation. Subsequently, a range of activities was conducted in the field including debris removal, eradication of invasive vegetation, installation of a clay cap and soil cover to several acres, planting turf grass and ornamental trees on capped areas, creation of small prairies, and installation of a hiking trail. Students gained academic credit for an 'immersive learning activity' that incorporated site assessment, data analysis, site planning, and map preparation using computer-aided design, as well as intensive field work. Similar applications of the reported restoration project may be applied to brownfields in other cities, potentially creating a series of spatially- or thematically-connected park spaces out of formerly unusable land.

Keywords: Brownfields, immersive learning, remediation, restoration

INTRODUCTION

Hundreds of thousands of brownfield sites have been documented throughout the United States (US EPA 2015), and an estimated 2250 occur in Indiana (IDEM 2017). A brownfield is defined as an 'abandoned, idled, or underused industrial or commercial site where expansion or redevelopment is complicated by real or perceived environmental contamination' (Edwards 2009). Such sites are often infertile and may be contaminated with heavy metals or other hazardous substances. The degree of contamination may pose a public health risk and is, at a minimum, detrimental to plant growth.

Remediation of brownfields can be carried out via several techniques, such as soil vapor extraction, soil washing, and chemical treatment. Many such technologies, however, permanently alter soil properties, employ costly systems, and require the use of hazardous materials (Li no date). Less invasive methods include capping with geomembranes and/or clay followed by placement of a topsoil layer.

Plant-based remediation technologies are considered a low-cost and effective treatment for many brownfields. Certain plant species have been found to remove potentially toxic metals from soil. In other cases, revegetation is preferred due to its benefits in preventing erosion by the action of water or wind, limiting runoff of metallic debris, and in creating an aesthetically pleasing site (US EPA 2006).

Brownfield soils commonly possess traits such as infertility, poor drainage, low organic matter content, and limited populations of indigenous microorganisms that cycle nutrients. Consequently, numerous studies have been carried out using municipal and industrial wastes as soil substitutes on drastically disturbed and/or contaminated soils (Pichtel et al. 1994; Halofsky & McCormick 2005; Pichtel & Bradway 2007).

In decades past Muncie, IN was home to numerous heavy industries; their subsequent closing and/or departure resulted in the presence of many derelict sites. One of these brownfields was the focus of a remediation project carried out by Ball State University (Muncie, IN) student teams over five years (2012 to 2017). The ultimate intent of the project was to redevelop an abandoned auto scrapyard to a community green space. Restoration of the property offered an opportunity for community enhancement. Easily accessible by public transportation and therefore available for public use, the site lies adjacent to the Cardinal Greenway, a rails-to-trails project, which provides standard recreational amenities.

A number of local organizations (e.g., neighborhood associations; the Red Tail Conservancy

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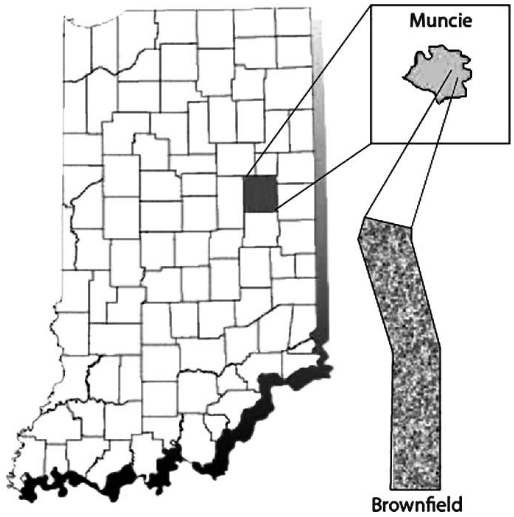

Figure 1.—Regional and local maps showing the study area.

Land Trust) expressed enthusiasm in creating green spaces for the neighborhood, and in converting this blighted brownfield site to beneficial use. Ultimately, the community surrounding the site will benefit from the transformed property by experiencing enhanced aesthetics, creation of valuable green space, increased property values, and by local citizens 'owning' the site.

Specific goals of the remediation were to (1) assess the impact of soil amendments and selected turf species in colonizing the infertile site; (2) remove automotive debris and other solid waste for proper disposal; (3) eradicate noxious and invasive vegetation; (4) establish selected tree and prairie species; (5) encourage wildlife by building appropriate structures; and (6) construct park amenities for future users. Actualization of these goals depended upon students involved in immersive learning who earned university-level credit for their contribution in transforming the site to an urban green space.

Immersive learning.—Ball State University's Immersive Learning program goes beyond school-sponsored service through internships. Distinctive characteristics, including student-driven projects, lasting outcomes, and community partnerships, set immersive learning apart from other experiential learning opportunities at the University. To be considered immersive, a project must:

- carry academic credit and focus on student learning outcomes
- engage participants in an active learning process that is student-driven but guided by a faculty mentor
- produce a tangible outcome or product, such as a business plan or policy recommendations
- involve at least one team of students, working on a project that is interdisciplinary in nature
- include community partners and create an impact on the larger community as well as on the student participants.

MATERIALS AND METHODS

The site.—The Indiana Brownfields List (IDEM 2012) was reviewed for potential sites within Delaware County, IN, that would be feasible for restoration. Using GIS mapping, prospective sites were ranked via the following criteria: (1) a registered brownfield located adjacent to areas considered disadvantaged and of high density; (2) near existing residential areas; and (3) accessible by public transportation. The site considered most suitable for the project was a former auto salvage yard in Muncie, IN (LAT/LONG: 40.1881°N / 85.3628°W). The site is located approximately 1.6 km southeast of downtown Muncie (Fig. 1).

The property had been used as a commercial and industrial facility since 1934. From 1934 to 1971 a bulk oil and gas storage facility, a refinery, and other businesses were active; two oil warehouses, two pump houses, two other buildings, ten gasoline tanks, and a large ammonia storage tank were previously housed on-site. From 1976 to 2002 the property was used as an automotive salvage yard. Following closure in 2002, substantial waste was left behind. A spill was reported on the site in 2003, a result of vandalized drums releasing grease and automotive fluids into soil. All contaminants along with affected soil and materials were excavated and removed from the site under orders of the Indiana Department of Environmental Management.

During an environmental site assessment (Symbiont 2008, 2009), tires, automotive parts, construction and demolition debris, two trailers, and general refuse were identified throughout the 2.1 ha site. There was evidence that unknown materials had been dumped and residues from oil and gasoline releases were detected. No aboveground or underground storage tanks were observed during the site investigation. Several soil/fill piles with unknown contents were located on the north side of the property and a wrecked office trailer was located on the southeast corner of the site.

Wetlands occur 1.3 km northeast of the site. No wetland delineation was carried out on the property. The site is not located in a flood zone; it is flat with sparse vegetation and exposed soil. Areas of standing water have been observed, likely from a high water table combined with poor drainage. Groundwater movement is to the north / northeast toward the White River. Soil type is classified as UfuA—Urban land-Millgrove complex, 0 to 1 percent slopes (USDA-NRCS, 2016).

Residential neighborhoods composed of standard single-family homes border the east and west of the site. A number of businesses occur directly to the south. This is primarily a family-based neighborhood that is showing signs of economic decline. Green spaces (e.g., parks) are severely limited in the area.

Environmental site assessment.—Student teams engaged in an extensive review of known site conditions, initially referring to phase I and phase II environmental site assessments (Symbiont 2008, 2009). The teams additionally referred to USDA-NRCS soil survey maps, geologic maps, Sanborn Fire Insurance maps, and other published data before going into the field. Teams subsequently engaged in extensive site reconnaissance. During site recon, soil material was collected and analyzed for various chemical parameters (i.e., plant nutrients, heavy metals; see below).

Prior to entry to the site, all students were trained in relevant aspects of site safety, including characteristics of hazardous chemicals, use of personal protective equipment, and potential site hazards. Students were required to read and sign a detailed Health and Safety Plan.

Plant tolerance and metal uptake.—The ability of several plant species, native to the Midwestern United States and showing promise in earlier studies to contribute to metal uptake and/or stabilization (Pichtel & Bradway 2007), were evaluated at the site. Plots measuring 2×3 m were established, and perennial ryegrass (*Lolium perenne* L.) was seeded at a 190 kg/ha rate (IN DOT 2015) and red clover (*Trifolium pretense* L.) at 100 kg/ha**.** Plots were amended with composted organic material which was derived from leaves and grass clippings, at a rate of 100 metric tons/ha. Soil was sampled from plots at the end of the growing season from the upper 20 cm and returned to the laboratory, where it was air-dried and sieved through a 2 mm mesh sieve.

Determination of soil K, Cd, Cr, Cu, Ni, Pb, and Zn was carried out after shaking 5 g of soil with 25 ml of 5 mM diethylenetriaminetriacetic acid (DTPA) on an oscillating shaker (120 osc./min) and measurement using flame atomic absorption spectrophotometry (FAAS) (Perkin-Elmer Analyst 2000, Norwalk, CT).

A subsample of soil from the plots was analyzed for particle size distribution using the hydrometer method (Day 1965). Organic carbon content was determined by loss on ignition at 360° C (Nelson & Sommers 1982) and pH in a 1:2 (w:v) soil:deionized water slurry. Soils were tested for soluble NO_3^- and NH_4^+ by the microplate method (GEN 5 Microplate Spectrophotometer Powerwave X5/X52 by BioTek). The organic compost was also tested for the above parameters.

Above-ground plant tissue was sampled 90 d after seeding. Tissue was cut $\sim$ 1–2 cm above ground surface and placed into paper bags where it was dried for 48 h at 105° C. A total of 0.5 g tissue was mixed with 10 ml of 75–80% concentrated HNO_3 and microwave-digested (MARS microwave digestor, CEM Corp., Matthews, NC). The method used for plant digestion was as follows: vessel temperatures were ramped to 190° C for 15 min with a holding period of 15 min at 800 W. The cooled digestates were diluted with 40 ml DI water and analyzed for Cd, Cr, Cu, Ni, Pb, and Zn using FAAS. Potassium concentrations were analyzed using ion chromatography (Dionex ICS 5000). A total of 4.9 µl of the tissue HNO_3 digestate was mixed with 100 µl of methanesulfonic acid and passed through a CS-19 cation exchange column prior to injection into the instrument.

Site restoration activities.—Since 2012 teams of Ball State University students with backgrounds in environmental management were recruited for the site restoration activity. Students were brought together in a so-called 'immersive learning' course through the university in order to gain academic credit from the experience. Five student teams, addressing different aspects of site remediation, have operated at the site over five years. Approximately 75 students have been involved in the project. Learning objectives for the immersive learning activity appear in Table 1.

A phased design and implementation plan for the space was formulated with different stages of

Table 1.—Learning objectives for the immersive learning activity.

Number	Outcome
1	Demonstrates a working understanding of core concepts (including principles, relationships, theories, and relevant laws of nature) applicable to the management of natural and man-made environments.
2	Respects and uses critical thinking skills and skeptical inquiry to assess potential environmental hazards and propose suitable responses.
3	Understands and applies valid and reliable scientific methods in the conduct of research.
4	Demonstrates proficiency and attention to safety in the use of analytical instrumentation.
5	Demonstrates proficiency in computer applications, including the compilation and analysis of data and the presentation of both data and analytical results.
6	Demonstrates a knowledge of professional ethics in the student's chosen field.
7	Demonstrates a command of written English to communicate technical information to scientific and lay audiences.
8	Understands and applies the relevant regulatory and policy requirements in the management of natural resources and the environment.

rehabilitation. The ultimate intent was to enhance local environmental quality as students worked together to redevelop the site. Activities included (1) debris removal; (2) eradication of invasive and nuisance plant species; (3) fence removal and replacement; (4) capping and installation of topsoil cover; (5) prairie establishment and encouraging wildlife; and (6) trail construction.

RESULTS AND DISCUSSION

Characterization of soil and compost.—Soil pH was 7.6 and soil total organic content (TOC) ranged from 0.6% to 13.1% with an average of 3.8% (Table 2). The study site is highly variable in terms of soil chemical and physical properties due to a wide range of industrial and commercial uses over almost a century (Symbiont 2009). It is suspected that TOC levels > 2% are due to anthropogenic inputs, e.g., improper release or disposal of fuels and lubricating oils (Cornelissen et al. 2005). Soil NO_3^- and NH_4^+ were 1.4 and 3.1 mg/kg, respectively, and K concentration was 1072.8 mg/kg (Table 2). Soil texture was a sandy loam. Compost TOC measured 36.8%. Compost concentrations of NO_3^-, NH_4^+, and K^+ were somewhat lower than those of soil (Table 2).

Soil Cd concentration was 6.3 mg/kg (Table 2). The Cd values are considered evidence of anthropogenic contamination (Kabata-Pendias 2001) since Cd concentrations of non-contaminated soils range from 0.1–0.5 mg/kg. Cadmium concentrations of contaminated soils can measure as high as >14,000 mg/kg (Gohre & Paszkowski 2006). At an Indiana Superfund site, Pichtel et al. (2000) measured 52 mg/kg soil Cd. Concentrations of soil Cu, Cr, Ni, Pb, and Zn were commensurate with those of local agricultural soils (Table 2).

Plant analyses.—Red clover did not become well established at the field plots. This may

Table 2.—Selected soil and compost chemical and physical properties. ($n = 4$.)

	pH	TOC	NO_3^-	NH_4^+	K	
	%		mg/kg			
Soil	7.6 ± 0.1	3.8 ± 1.2*	1.4 ± 0.9	3.1 ± 2.4	1072.8 ± 52.3	
Compost	7.5 ± 0.01	36.8 ± 5.8	0.9 ± 0.1	2.5 ± 0.1	716.5 ± 51.0	
	Cd	Cu	Cr	Ni	Pb	Zn
	mg/kg					
Soil	6.3 ± 2.3	131.4 ± 17.7	15.4 ± 8.6	23.2 ± 3.7	55.0 ± 39.0	334.5 ± 78.5
Compost	1.3 ± 1.0	70.1 ± 7.8	3.8 ± 3.6	3.5 ± 1.5	15.7 ± 12.5	76.5 ± 52.2

* Range 0.6 - 13.3%.

Table 3.—Metal concentrations, ryegrass tissue. BDL* = below detectable limit.

Cd	Cu	Cr	Ni	Pb	Zn
		mg/kg			
BDL*	124.5 ± 33.3	33.3 ± 17.8	72.8 ± 20.5	226.4 ± 217.9	303.5 ± 80.1

have been due, in part, to a significant drought occurring during part of the growing season. Furthermore, invasive species became established on many plots and may have suppressed clover growth.

Ryegrass tissue Cd concentration was below detectable limits (Table 3). Tissue Cu and Cr measured 124.5 and 33.3 mg/kg, respectively. Tissue Ni, Pb, and Zn were 72.8, 226.4, and 303.5 mg/kg, respectively. The quantity of tissue Pb is a promising indicator for phytoextraction. This species, however, does not qualify as a hyperaccumulator of soil Pb. A hyperaccumulator is defined as a plant that has the ability to accumulate extraordinarily high amounts of heavy metals in the aerial organs, far in excess of the levels found in the majority of species, without suffering phytotoxic effects (Rascio & Navari-Izzo 2010). Previous studies have demonstrated that perennial ryegrass has the potential for the rehabilitation of Cd- or Pb-contaminated soil (Arienzo et al. 2004; Si et al. 2006).

The ryegrass had poor coverage on infertile soil material; however, average coverage percentage on plots amended with compost was 75% (data not tabulated). Ye et al. (2000) found that Italian ryegrass (*Lolium multiflorum* Lam.) experienced a higher percent coverage of test plots when grown with a soil amendment barrier of fly ash or combusted coal residue as compared to bare soil.

Site restoration.— *Debris removal*: Removal of automobile debris and other solid waste was carried out by Ball State University students; on one occasion, several persons required to engage in community service were brought to the site, courtesy of Delaware County Community Corrections. Work teams transported waste to roll-off dumpsters provided by the City of Muncie. At least 20 large roll-off dumpsters (38 m^3 volume each) were filled and removed for disposal. In 2013 the abandoned office trailer was demolished by city crews using conventional heavy equipment.

Eradication of invasive and nuisance plant species: The site was overgrown with invasive species of perennial shrubs and trees including Asian bush honeysuckle (*Lonicera maackii* (Rupr.) Maxim.), multiflora rose (*Rosa multiflora* Thunb.), stinkweed (*Thlaspi arvense* L.), Tree of Heaven (*Ailanthus altissima* (Mill.) Swingle), Siberian elm (*Ulmus pumila* L.), cottonwood (*Populus deltoides* Marshall), poison ivy (*Toxicodendron radicans* (L.) Kuntze), among others. As many invasive plants occurred alongside fences, they could not be effectively removed by a Bobcat® tractor; hence, they were cut using chainsaws and/or loppers. Student teams decided that chemical treatments were not to be used for plant removal.

Fence removal and replacement: A 3 m tall corrugated steel perimeter fence along portions of the property was dismantled manually. This process was preferred rather than using heavy equipment in order to support recycling of useful components such as heavy wooden beams and sheet metal, and to keep costs under control. On the south end of the property a split rail fence was installed. A split rail gate for possible future pedestrian traffic was included. Due to the extreme density of the underlying soil material, a gas-powered auger was necessary to drill holes for fence posts.

Capping and topsoil cover: The surface of the site was restored sequentially in 0.4 hectare (1 acre) sections. First, the surface was scraped using a Bobcat tractor in order to (1) remove debris occurring within the top 0.5 m for eventual removal; (2) create a level or contoured surface (depending on location); and (3) remove additional unwanted vegetation. Following scraping, local clay material was delivered. Clay piles were spread using a Bobcat to a depth of 0.5 m and subsequently compacted. The clay cap was covered with topsoil, which was spread to a depth of 0.5 m using the Bobcat. Straw was immediately placed over the exposed soil to prevent erosion by water or wind.

Plant establishment and support of wildlife: Immediately following placement of straw onto soil, turf grass seed was applied. Perennial ryegrass in combination with red clover was selected. Seed was distributed using a mechan-

Table 4.—Species of grasses and flowering plants installed in the four prairies.

Common name	Scientific name
Big bluestem	*Andropogon gerardii* Vitman
Switchgrass	*Panicum virgatum* L.
Prairie oval sedge	*Carex bicknellii* Britton
Side-oats grama	*Bouteloua curtipendula* (Michx.) Torr.
Nodding wild onion	*Allium cernuum* Roth.
Heath aster	*Symphyotrichum ericoides* (L.) G.L. Nesom var. *ericoides*
White false indigo	*Baptisia alba* (L.) Vent. var. *macrophylla* (Larisey) Isely
Purple coneflower	*Echinacea purpurea* (L.) Moench
Rattlesnake master	*Eryngium yuccifolium* Michx.
Downy sunflower	*Helianthus mollis Lam.*
False sunflower	*Heliopsis helianthoides* (L.) Sweet
Foxglove beardtongue	*Penstemon digitalis* Nutt. ex Sims
Purple prairie clover	*Dalea purpurea* Vent.
Yellow coneflower	*Ratibida pinnata* (Vent.) Barnhart
Butterflyweed	*Asclepias tuberosa* L.
Rosinweed	*Silphium integrifolium* Michx.
Compass plant	*Silphium laciniatum* L.
Sky blue aster	*Symphyotrichum oolentangiense* (Riddell) G.L. Nesom var. *oolentangiense*
Riddell's goldenrod	*Solidago riddellii* Frank ex Riddell
Rough blazingstar	*Liatris aspera* Michx.
Round-headed bushclover	*Lespedeza capitata* Michx.

ical seed spreader. The newly-established vegetation was allowed to grow to about 20 cm tall, which encouraged formation of a dense root mat. Following initial mowing, the grass was mowed on an as-needed basis. Turf was watered by rainfall only.

Several ornamental and fruit trees were purchased locally for planting. Species included flowering dogwood (*Cornus florida* L.), sweetgum (*Liquidambar styraciflua* L.), Yoshino flowering cherry (*Prunus* × *yedoensis* Matsum.), quaking aspen (*Populus tremuloides* Michx.), and Shumard oak (*Quercus shumardii* Buckley).

Students identified four areas for establishment of tall grass prairies. The seedbed was prepared both manually and with a rototiller. Seeds and live seedlings (Table 4) were purchased from local sources.

Students constructed several bird, bat, and butterfly houses that were subsequently installed around the property.

Trail construction: Hiking trails were installed throughout the site. The trails begin at the south entrance and extend through the woodlot. Initially, teams manually cleared small trees and stumps using chain saws and loppers. This was followed by a Harley® rake attached to a Bobcat tractor to clear the smaller vegetation across a width of 2 m. The cleared area was covered with hardwood chips, provided by Ball State University, to a depth of 20 cm. The layout of the property is shown in Fig. 2.

CONCLUSIONS

A former brownfield in Muncie, Indiana has undergone extensive improvement in terms of environmental quality, safety, and aesthetics. Surface debris has been removed; barren soil has been capped by a thick clay and soil cover; and lawn, prairie and ornamental plantings now predominate on much of the property. In essence, the restored site now serves as an asset, rather than a liability, for the local community.

The project relates to the Ball State University Strategic Plan as follows:

1. Ball State University has pledged to offer "action-oriented learning, including immersive out-of-class experiences". In this project student teams actively participated in the product by designing, planning, and constructing the new facility. A significant input of time and expertise has come together to formulate an attractive, community-friendly property.
2. The university is to "Embrace and support partnerships and collaborations across the institution and with the greater external community". This goal was achieved via

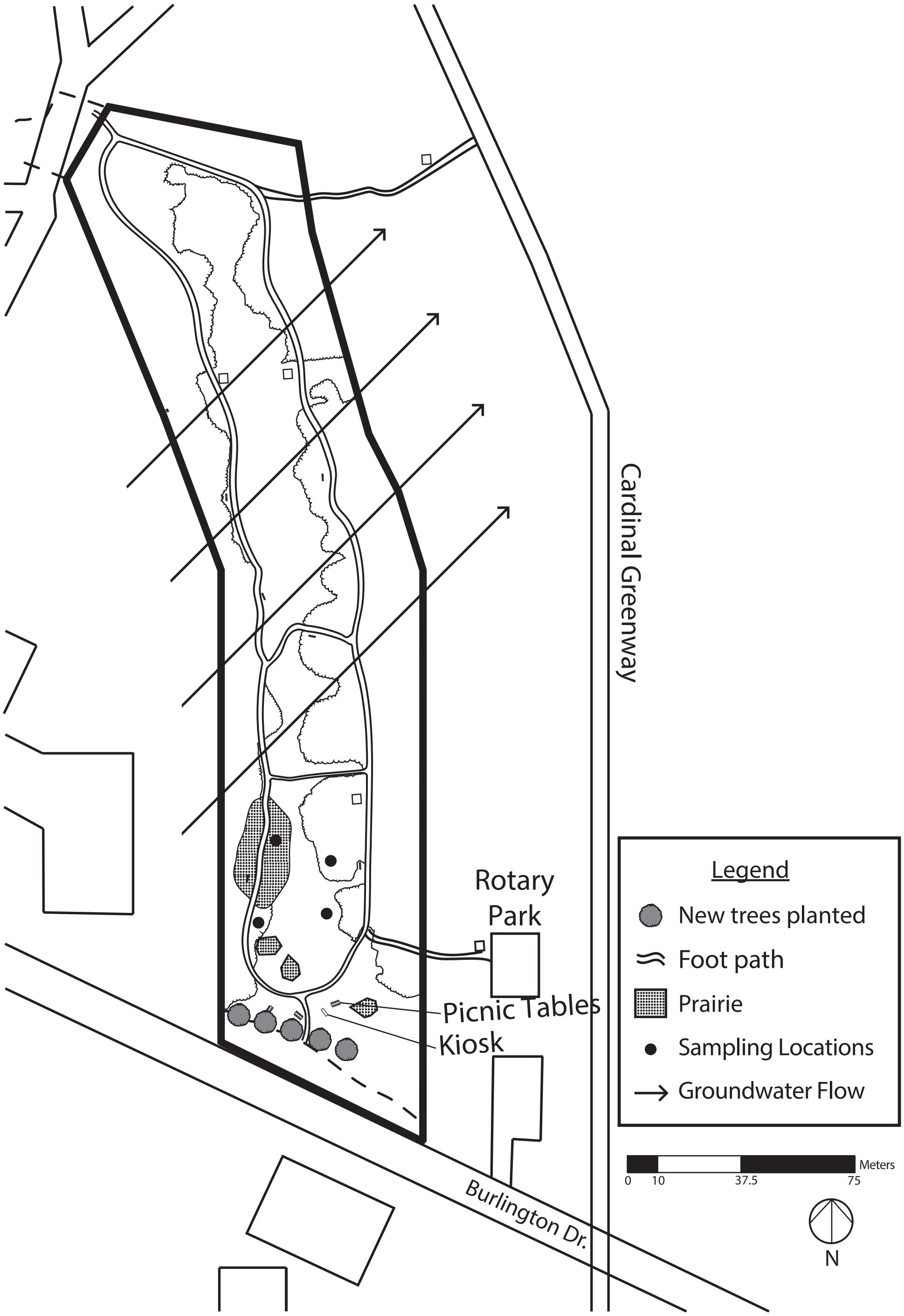

Figure 2.—Current layout of the site showing various improvements.

regular interaction with community organizations regarding site planning and implementation. Long-term collaboration is encouraged for on-going site maintenance and enhancement. Avenues will be sought for redevelopment work at nearby sites.

3. The Ball State University Strategic Plan for 2012–2017 offers the goal: "Continue to position the university as a steward of the environment by building on the university's expertise and success in sustainability." The redevelopment work clearly aligns with the concept of sustainability. According to US EPA (2014), sustainability "creates and maintains the conditions under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic and other requirements of present and future generations".

The reported project has served as a highly effective learning experience for Ball State University students. Knowledge and skills were gained in computer-aided design, environmental planning, plant ecology, soil science, and site remediation. Both team and communication skills were enhanced among students. Throughout this experience, students described their immersive learning experience as 'a valuable way to understand underlying concepts'; 'more interesting', and 'a better way to retain facts and data'…. as compared with classroom-based instruction. Additionally, students appreciated working on their own in planning the future of the site.

The study demonstrates that a former brownfield is capable of being revegetated by common turf species. It is emphasized, however, that each infertile and/or toxic site must be assessed for revegetation species on a case-by-case basis.

Dedicated work goes on at the site; Ball State students continue to augment professional skills as well as gain academic credit while enhancing the quality of the property.

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