



## Appendix H | **2023 City of New Braunfels Reports**



## **Appendix H1 | Native Aquatic Vegetation Restoration in the Comal River System**



## **2023 Native Aquatic Vegetation Restoration and Maintenance in the Comal River**



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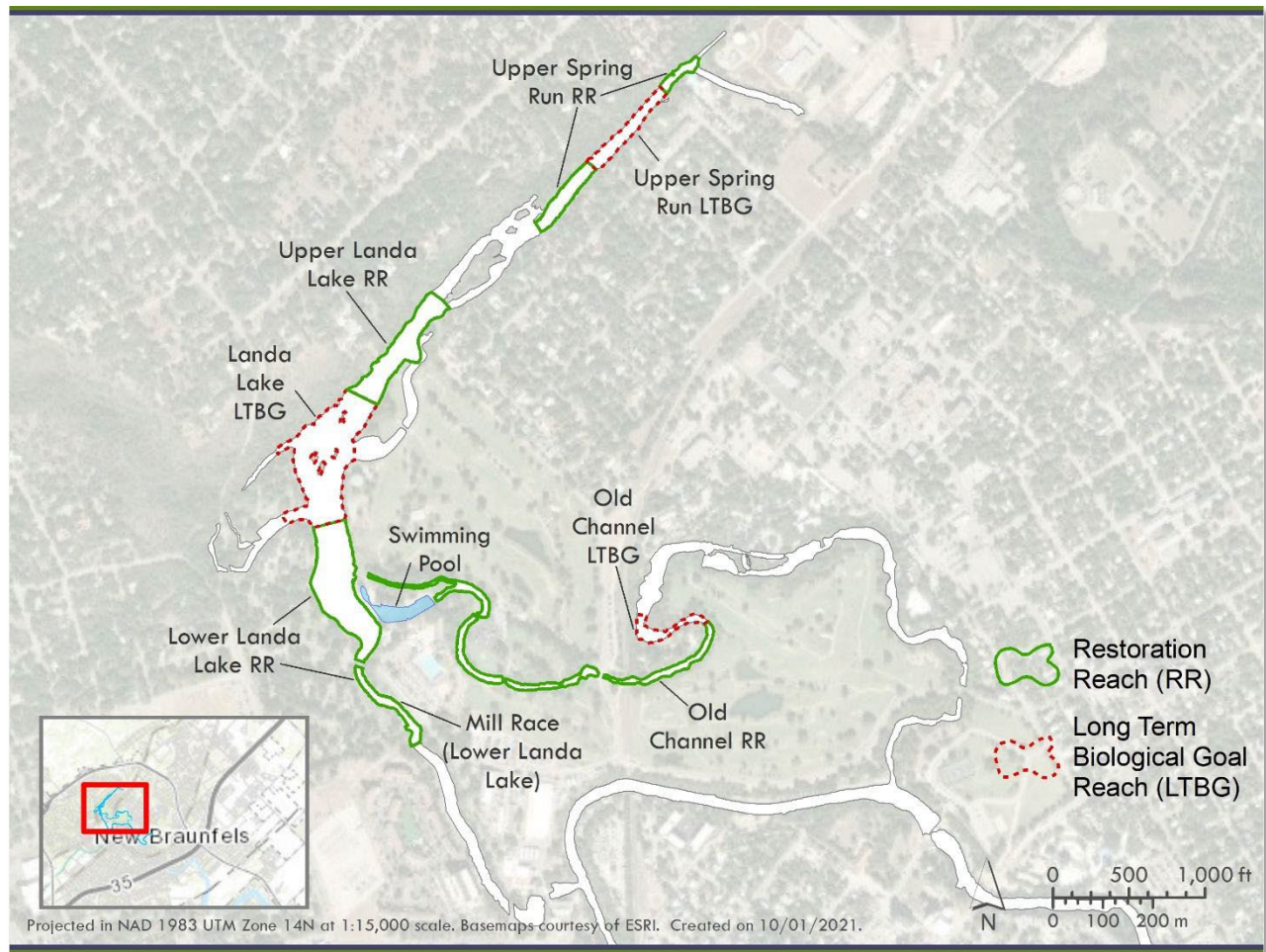
# 1 Introduction

As part of the Edwards Aquifer Recovery Implementation Program (EARIP) Habitat Conservation Plan (HCP), scientists at BIO-WEST, Inc. (BIO-WEST) have conducted native aquatic plant restoration activities to improve habitat for the federally listed, endangered Fountain Darter (*Etheostoma fonticola*) and native aquatic fauna. This year marked the tenth consecutive year for restoration and maintenance activities. The continued intent of this HCP measure is to increase the cover and distribution of target native aquatic plant species, subsequently benefiting the Fountain Darter by increasing available native habitat and improving the quality of existing habitat. This report summarizes the activities and restoration results within the project areas for 2023.

## 1.1 Project Areas Overview

The project area covers the upper two kilometers of the Comal River but is divided into multiple Restoration and Long Term Biological Goal (LTBG) Reaches (**Figure 1**). LTBG Reaches are the sampling sites in which routine biological monitoring is conducted. Fountain Darter sampling, water quality, discharge and various other data are collected specifically in the LTBG Reaches to support the HCP long-term monitoring program. The Restoration Reaches are included to expand restoration and habitat improvement in the system. The project area encompasses Blieiders Creek through a spring run channel, referred to as Upper Spring Run, into lower Landa Lake. The project area also extends into the Old Channel and downstream approximately 1,100 meters from Landa Lake Dam. Each project reach has its own restoration timeline and goals as directed by annual work plans provided by the City of New Braunfels.

In 2023, work on the project was limited due to the continuing drought and subsequent low spring discharge which continued from 2022. Condition M of the HCP limits restoration work in all project areas once the Comal River discharge drops below 130 cfs. This trigger went into effect in July of 2023 and remained in effect for the majority of the work year. Work which could be completed was mostly focused in the Landa Lake LTBG Reach and Old Channel Restoration Reach where the team continued to maintain previously restored areas via gardening



**Figure 1** Location of the Landa Lake, Upper Spring Run and Old Channel Long Term Biological Goal (LTBG) Reaches (outlined in red). Green outlines the restoration areas.

and vegetation mat removal. No large-scale removal or plantings occurred this year. The team did not utilize the Mobile underwater plant propagation trays (MUPPTs) and moved the benthic barriers only once before Condition M criteria were triggered. The minimal planting that did occur involved hand sprigging in localized areas to maintain cover, hand clearing small amounts of vegetation to maintain buffers and clearing vegetation mats and algae by hand or with dive scooters.

Our maintenance and gardening activities in Landa Lake and the Old Channel allowed for a healthy native vegetation community to persist for most of the year despite low flows. The vegetation community in the Upper Spring Run Reaches changed somewhat with *Cabomba caroliniana* (Cabomba), the macroalgae *Chara* and filamentous algae becoming more

commonplace while bryophytes disappeared almost completely. The Old Channel LTBG and Restoration reaches varied from previous years with the loss of Cabomba as a major constituent. Coverage of other species shifted. The Old Channel LTBG reach was the only stretch within our work areas where bryophyte remained abundant. As is common each year, general maintenance such as vegetation mat removal, tree trimming and clearing of debris was conducted as needed across the project area to enhance habitat quality for native aquatic vegetation.

## 2 Spring / River Conditions in 2023

This project year was dominated by below average flows from continuing drought. Precipitation recorded for the months of March, April and May at the San Antonio International Airport totaled 9.98 inches. As of November 1, rainfall totaled 17.5 inches. Comal River discharge fluctuated between 100 cfs and 150 cfs during the first quarter of the year, well below the monthly means. Late spring rains allowed for some recovery, but discharge began to drop quickly during June and July. In July, Comal spring discharge dropped below the 130 cfs mark, enacting Condition M of the Habitat Conservation Plan. All three spring runs ceased flowing from their headwaters. For an extended period of time, only Spring Run 3 flowed at all. As a result, all large-scale restoration activities were halted. This included large scale plantings, plant removal, and benthic barrier relocation. Through August, discharge hovered around 60 cfs and dropped below the 60 cfs level for a short period (**Figure 2**). At this time, water ceased flowing over the New Channel weir (**Figure 3**). The water level of Landa Lake was approximately two feet lower than average. The Three Islands area in the center of Landa Lake became dewatered in some locations. Conditions improved toward the latter part of the year, but Condition M remained in effect to the submittal of this report.

## 3 Plant Propagation Methods

The native aquatic plant species targeted for this project include: *Ludwigia repens* (Ludwigia), Cabomba, *Sagittaria platyphylla* (Sagittaria), *Potamogeton illinoensis* (Potamogeton) and *Vallisneria neotropicalis* (Vallisneria). Currently, only Ludwigia, Cabomba and Potamogeton are propagated and planted. Sagittaria and Vallisneria have shown to be ultra-competitive species and need no assistance in maintaining cover and can self-propagate effectively. In some areas,



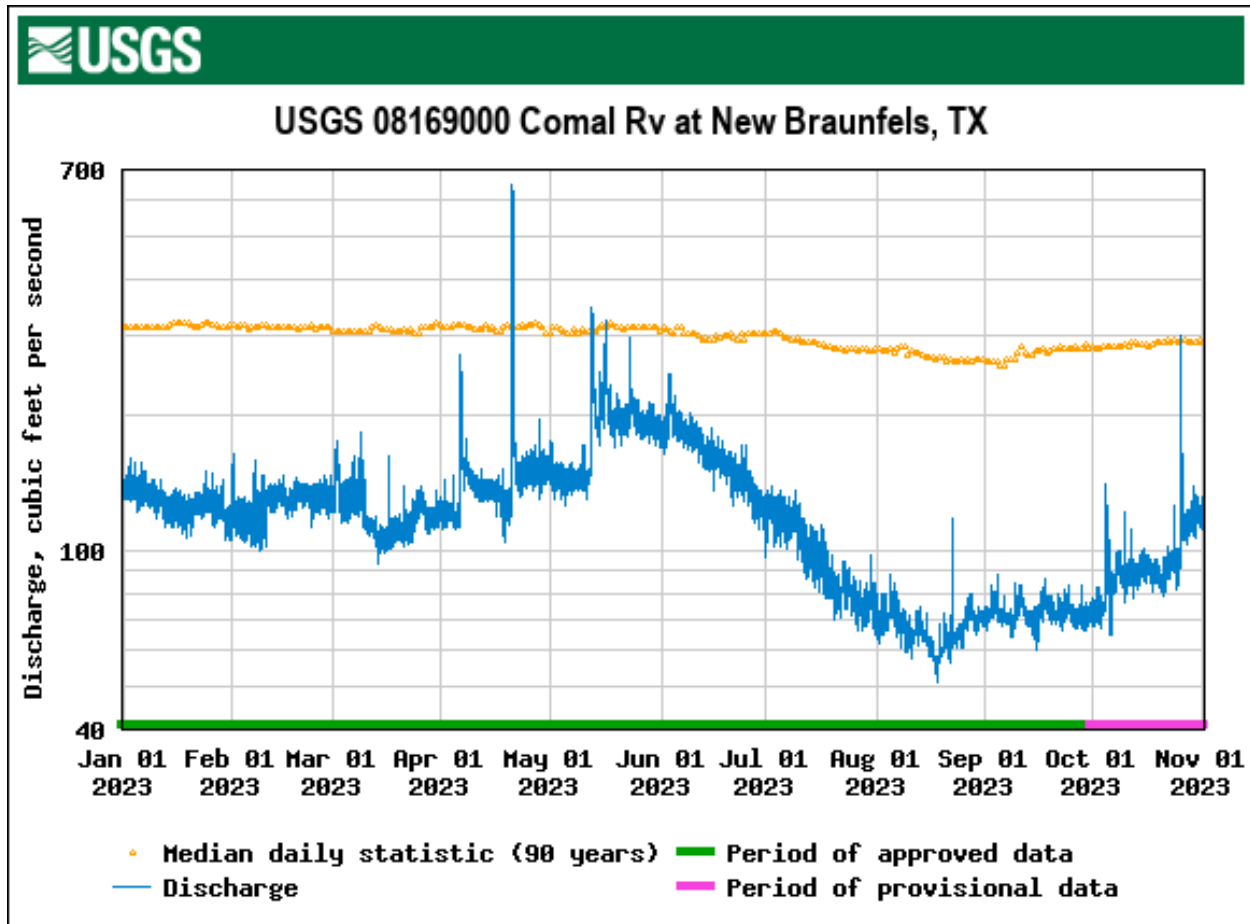


Figure 2 Discharge in the Comal River from January through November 2023 (USGS 2023).



Figure 3 The New Channel stopped flowing at the weir in August.

Sagittaria and Vallisneria have met the target goals in their respective reaches or are deemed not appropriate for a specific area. The methods for aquatic plant propagation in 2023 was altered due to the ongoing drought and Condition M. Mobile underwater plant propagation trays were not utilized in 2023. Normally, the MUPPTs are cycled at least three times in a year. Instead, hand sprigging supplemented existing Ludwigia and Cabomba colonies and was used to start some new colonies. Sprigs are derived from trimmed stem fragments. The past several years have demonstrated that trimming Ludwigia and Cabomba improves the health of the stands, reduces vegetation mats and encourages plants to spread. Sprigs trimmed from plants can also be planted to start new plants and are also a reliable way to supplement Ludwigia and Cabomba colonies. Detailed background information regarding plant propagation methods can be found in previous reports (BIO-WEST 2013b, 2014, 2015, 2016).

## 4 Aquatic Vegetation Restoration Program

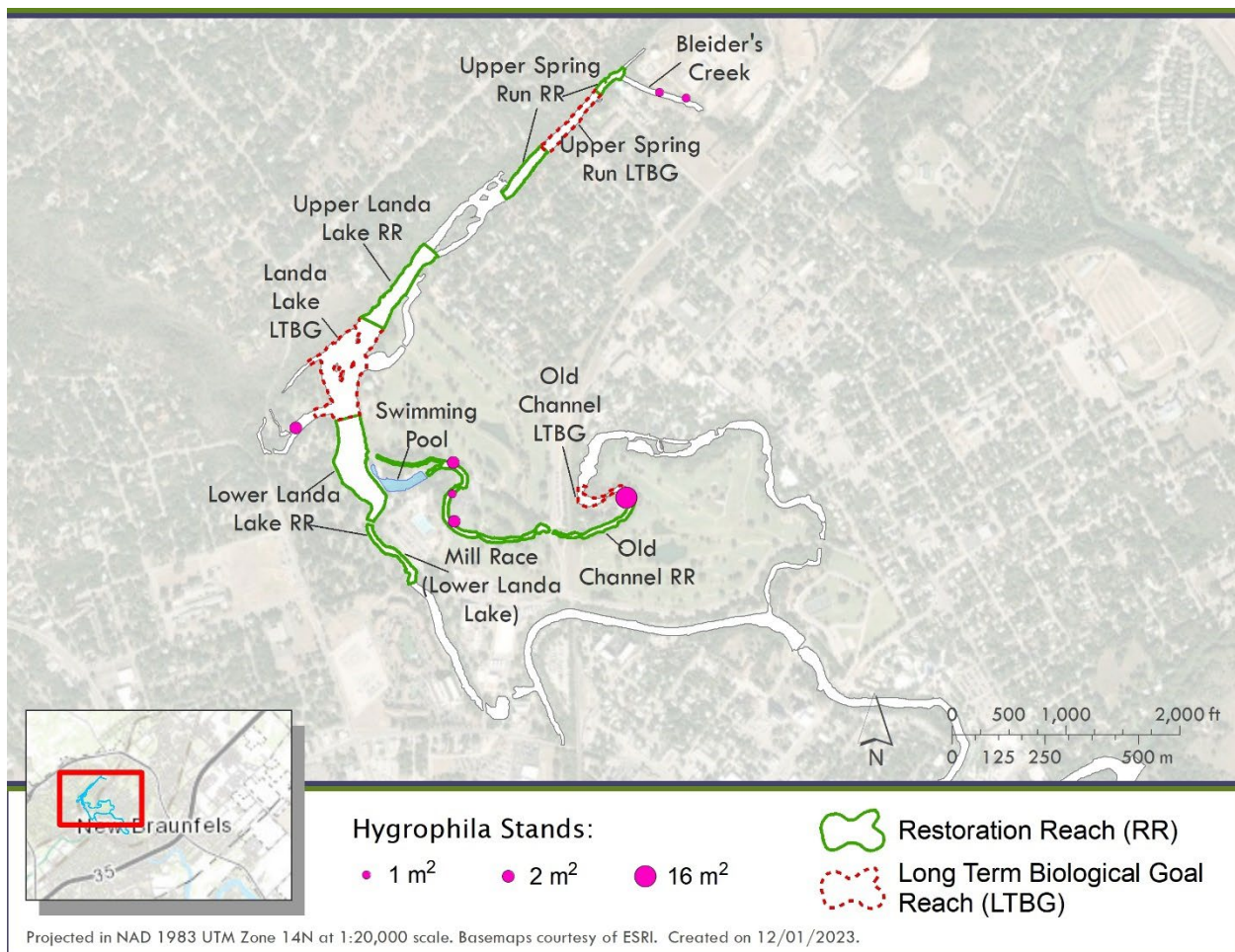
Aquatic habitat restoration field efforts in the project areas consist of three main activities: 1) removal of invasive *Hygrophila polysperma* (Hygrophila); 2) planting of native aquatic plants; and 3) monitoring, mapping and gardening of restored areas. Each activity is covered in detail in sections 4.1–4.3.

### 4.1 Hygrophila Removal

From 2013 to 2018, significant effort was put into removing and eliminating Hygrophila from Blieders Creek, Upper Spring Run, Landa Lake and the first kilometer of the Old Channel Restoration Reach. Since 2019, the presence of Hygrophila has been greatly reduced and is now found in only a few locations in the project area but persists. Typical occurrences of Hygrophila are now limited to sprigs or small clumps, about a meter in diameter or smaller and usually along the stream edges (**Figure 4**).

To continue to combat Hygrophila, the project team routinely conducted visual snorkel and wading surveys from Blieders Creek to the end of the Old Channel LTBG Reach and any Hygrophila observed was removed. Greater effort was focused on the Old Channel river sections adjacent to the golf course as these areas tend to have recurring Hygrophila fragments and occasional reoccurring patches. About 22 square meters (m<sup>2</sup>) of Hygrophila was removed from the project





**Figure 4** The 2023 distribution of Hygrophila in the study area.

area along with a couple additional m<sup>2</sup> from Blieders Creek during 2023 (Table 1). Several patches were located in Old Channel and Spring Run 1 of Landa Lake over the course of the year. These were subsequently removed as they were observed. In Blieders Creek, two reoccurring patches were removed toward the end of the year. The likelihood of re-infestation in restored areas is possible. Hygrophila is currently expanding upstream into the Old Channel LTBG Reach and will need to be removed in bulk as soon as flow conditions allow. Ongoing maintenance and occasional gardening will prevent Hygrophila from re-establishing and dominating the project areas. Thus far, containment has proven possible and successful. Dramatic reinfestation is unlikely so long as periodic gardening and removal efforts continue. **Table 1** summarizes Hygrophila removal activities for 2023.

**Table 1 Amount of Hygrophila removed in 2023 per work section**

Location/Section	Area Removed (m <sup>2</sup> )	Period of Work
Landa Lake (outside of LTBG Reach)	1	Gardened as needed
Old Channel Restoration Reach	5	Gardened as needed
Old Channel LTBG Reach	16	Gardened as needed
Swimming Pool	0	Gardened as needed
Upper Spring Run LTBG Reach	0	Gardened as needed
Upper Spring Run Restoration Reach and Blieders Creek	2	Gardened as needed
Landa Lake Spillway	0	Gardened as needed

## 4.2 Native Aquatic Plant Restoration

Over the course of 2023, the Comal aquatic restoration project planted 7,256 native aquatic plants. The team placed 1,020 sprigged *Ludwigia* into Landa Lake and 1,340 sprigged *Ludwigia* into the Old Channel. No rooted plants were provided from MUPPTs. In Landa Lake there were 386 planted. Cabomba plantings consisted of 4,300 sprigged plants placed into Landa Lake. No Cabomba was planted into the Old Channel. To date, the project has planted 92,774 aquatic plants for Fountain Darter habitat restoration. A majority of plantings were completed between January 1 and June 26 and before Condition M was implemented. Planting of smaller quantities of plants continued while Condition M was in place. Sprigging can occur using only one or two people snorkeling and minimal disturbance of the substrate.

## 4.3 Aquatic Gardening and Monitoring

As previously discussed, no large-scale removal of *Hygrophila* was necessary for 2023. Instead, only routine gardening trips were conducted at Blieders Creek and Old Channel Restoration and LTBG Reaches to search for *Hygrophila* sprigs or patches. With *Hygrophila* mostly absent, aquatic gardening focused on other objectives, including regular trimming of emerged *Ludwigia* stands in Landa Lake, clearing floating vegetation mats, clearing algae, and removing fallen trees or other debris. Trimming the *Ludwigia* provides the sprigs for plantings while also promoting persistence of individual patches by reducing the top growth of the *Ludwigia* plants and lessening buoyancy of the patches. *Ludwigia* stands that have a high degree of top growth, sometimes extending three to four feet into the water column, tend to be uprooted by water currents over time. Therefore, removal of top growth aids in persistence of these patches. These trimmings are then replanted as sprigs.

Other gardening in these reaches entailed hand removal of *Vallisneria* and *Sagittaria* around the perimeter of *Ludwigia* and *Cabomba* patches to control encroachment.

The general gardening activities discussed above were conducted throughout Condition M. Activities which were halted during Condition M including producing and planting MUPPT-grown plants, moving benthic barrier mats and removing large areas of *Vallisneria* or *Sagittaria* to prepare planting plots. Clearing of vegetation mats in the immediate vicinity of restored vegetation continued. Vegetation mats and algae became less of a problem later in the year despite the lower than average spring discharge. One contributing factor to this may have been the decreasing growth rate of *Vallisneria* and *Sagittaria* as flows continued to drop and carbon dioxide (CO<sub>2</sub>) availability became more limited. Similar observations in reduced growth rate were noted based on how slowly these two species grew back into the buffer areas maintained around restored *Ludwigia* and *Cabomba* patches. As flows decreased and stayed consistently low, the project team needed to clear these buffer areas less frequently.

Vegetation mats are rarely a problem in the Old Channel Restoration Reach and emerged *Ludwigia* growth is also not an issue since water depth is lower and current velocities are greater than in other reaches. These two factors typically keep *Ludwigia* stems short and sprawling in the Old Channel. Aquatic gardening activities in the Old Channel focused on removing fallen trees or tree limbs which block the channel and facilitate the accumulation of debris. These activities were conducted again in 2023.

Monitoring and mapping LTBG and Restoration Reaches is an important restoration strategy as it provides data useful in gauging the progress of the project and allows the team to reassess and enhance methodologies for future success. Four mapping events were conducted in 2023 to evaluate the restoration project and assess native plant coverages. The first was a baseline mapping event conducted in January, before 2023 restoration activities commenced. Subsequent mapping occurred in April, July and October. Vegetation mapping is conducted by encircling the perimeter of plant patches with a kayak while collecting GPS coordinates via a Trimble GPS unit. Once a patch is mapped it is identified to species, and the density of each species within the patch is estimated to produce a final area coverage estimate in m<sup>2</sup>. These methods are used to quantitatively evaluate the spatial expansion of plant species and qualitatively evaluate the

density and health of restored and natural stands. The results of these mapping events are discussed in detail in the respective site results sections below.

## **4.4 2023 Restoration Results**

### **4.4.1 Old Channel Restoration Results**

The Old Channel reaches have shown to be self-sustaining and diverse over the past several years. A mixed diversity of species dominates the area above Elizabeth Street while single species patches of Cabomba, Ludwigia and Sagittaria have been successful in the area below Elizabeth Street. Between patches of rooted vegetation, beneficial benthic algal mats of *Cladophora*, *Rynchospora* and bryophyte dominate along with some bare substrate. For the last two years, Ludwigia and Cabomba have maintained sufficient growth without plantings. However, this year was different. Cabomba waned very early in the year, disappearing by spring. There are limited sites for the Cabomba population in the Old Channel and all decreased substantially. Cabomba in the LTBG Reach completely disappeared as a direct result of concentrated bryophyte masses settling on top as flows slowed down. Ludwigia patches were impacted and reduced too as a likely result of changing velocity patterns due to lower water levels and fallen trees. Since Condition M was enacted for most of the work year, the project team only supplemented some Ludwigia areas. No large-scale planting occurred in any portions of the Old Channel LTBG or Restoration Reaches. Additionally, the project team only gardened for Hygrophila and removed some fallen trees and branches.

The Old Channel Restoration Reach and LTBG Reach still requires manipulation to promote Cabomba and Ludwigia towards coverage goals. Due to the activation of Condition M, only a short window of time was available for progress to be made in the reach. No new restoration plot was added for the year.

A total of 1,340 Ludwigia plants were planted as supplemental plantings throughout the Old Channel Restoration Reach (**Table 2**).

**Table 2**      **Planting dates and number of target species planted within the Old Channel**

2023 Old Channel Restoration Plantings			
Old Channel Restoration Reach			
Date Planted	Plot	Ludwigia	
3/6	Supp.	180	
3/8	Supp.	160	
4/13	Supp.	250	
4/27	Supp.	140	
7/6	Supp.	30	
7/7	Supp.	160	
7/10	Supp.	200	
7/13	Supp.	160	
7/14	Supp.	60	
Total		1,340	

**Table 3** shows baseline, spring, July (low flow) and fall coverages (m<sup>2</sup>) of the target species within the Old Channel Restoration and LTBG Reaches. As noted in previous reports, Ludwigia and Cabomba often fluctuate between mapping events across the year, while the coverage of Vallisneria and Sagittaria tends to stay consistent. Inter- and intra-year fluctuations result from natural losses, competition and expansion in addition to restoration plantings.

In the Old Channel LTBG Reach, Ludwigia coverage trended downwards over the course of the year, then started rebounding by fall 2023 but not back to fall 2022 levels (Table 3). Based on observations, this was partially a result of some scour brought on by several fallen trees which altered the velocity pattern upstream of the Ludwigia patches. Bryophyte coverage expanded over some of the same area where Ludwigia occurred in the reach. Cabomba experienced a complete collapse between fall of 2022 and early 2023. The team was hopeful that the Cabomba would recolonize on its own, but after nine months, it had not yet reappeared. The area, once colonized by Cabomba, was dominated by dense bryophyte beds this year which provided high quality Fountain Darter habitat. (**Table 3**).

In the Old Channel Restoration Reach, Ludwigia stayed relatively consistent while Cabomba coverage almost disappeared. Of the two patches of Cabomba in this reach, one was overtaken by Potamogeton and the other was covered in bryophyte. During 2023, the entire Old Channel remains a healthy and functional reach which provides ample habitat for Fountain Darters. When Condition M is removed, the project team will begin replanting efforts to regain

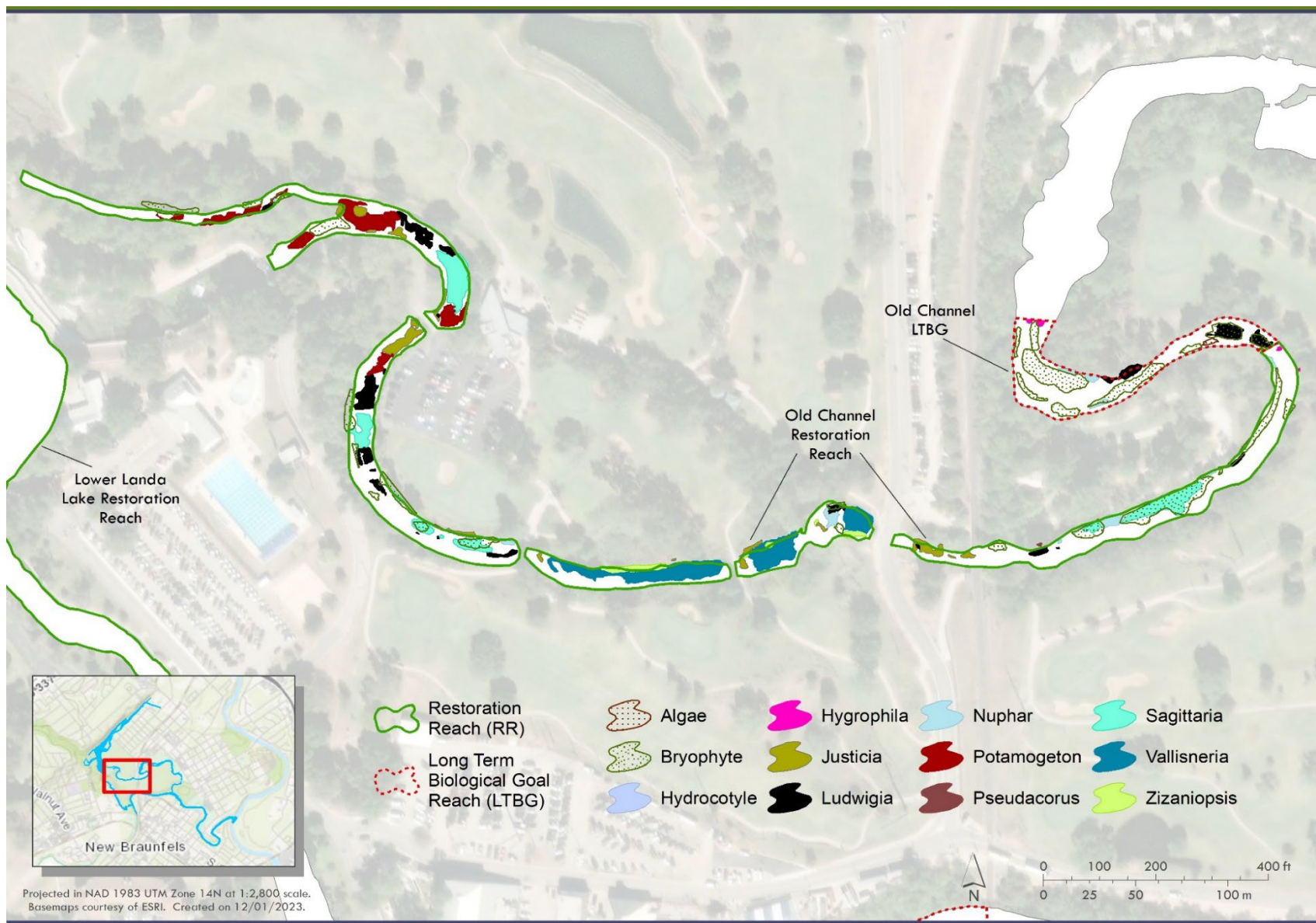
Ludwigia/Cabomba patches from competition in order to expand desired species cover and strive towards meeting HCP goals.

Maps highlighting the species distribution between all four mapping events in 2023 are shown below (**Figures 5, 6, 7, 8**).

**Table 3      Seasonal cover (m<sup>2</sup>) of target restoration species in the Old Channel LTBG and Restoration Reaches from GIS mapping from September 2022 to October 2023.**

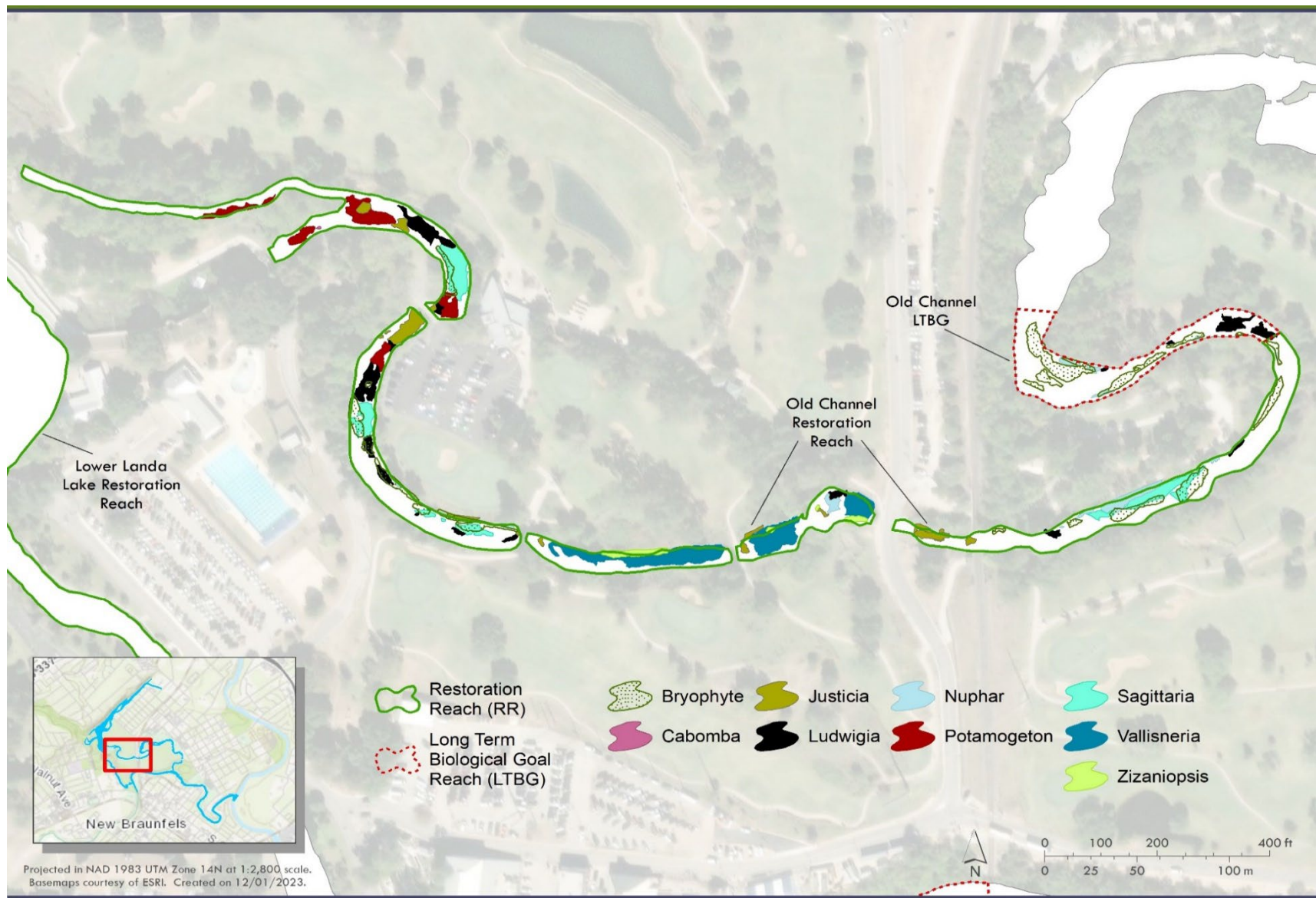
Species	Sept. 2022	Jan. 2023	April 2023	July 2023	Oct. 2023
Old Channel LTBG Reach					
Ludwigia	290	128	129	111	152
Cabomba	485	0	0	0	0
Hygrophila	0	16	0	0	0
Bryophyte	568	718	549	507	580
algae	54	13	0	67	37
Old Channel Restoration Reach					
Ludwigia	605	477	507	419	428
Sagittaria	785	819	784	848	726
Cabomba	132	1	1	6	29
Potamogeton	540	554	500	577	878
Vallisneria	847	995	1004	992	812
Hygrophila	0	5	0	0	0
Bryophyte	726	1055	769	582	707



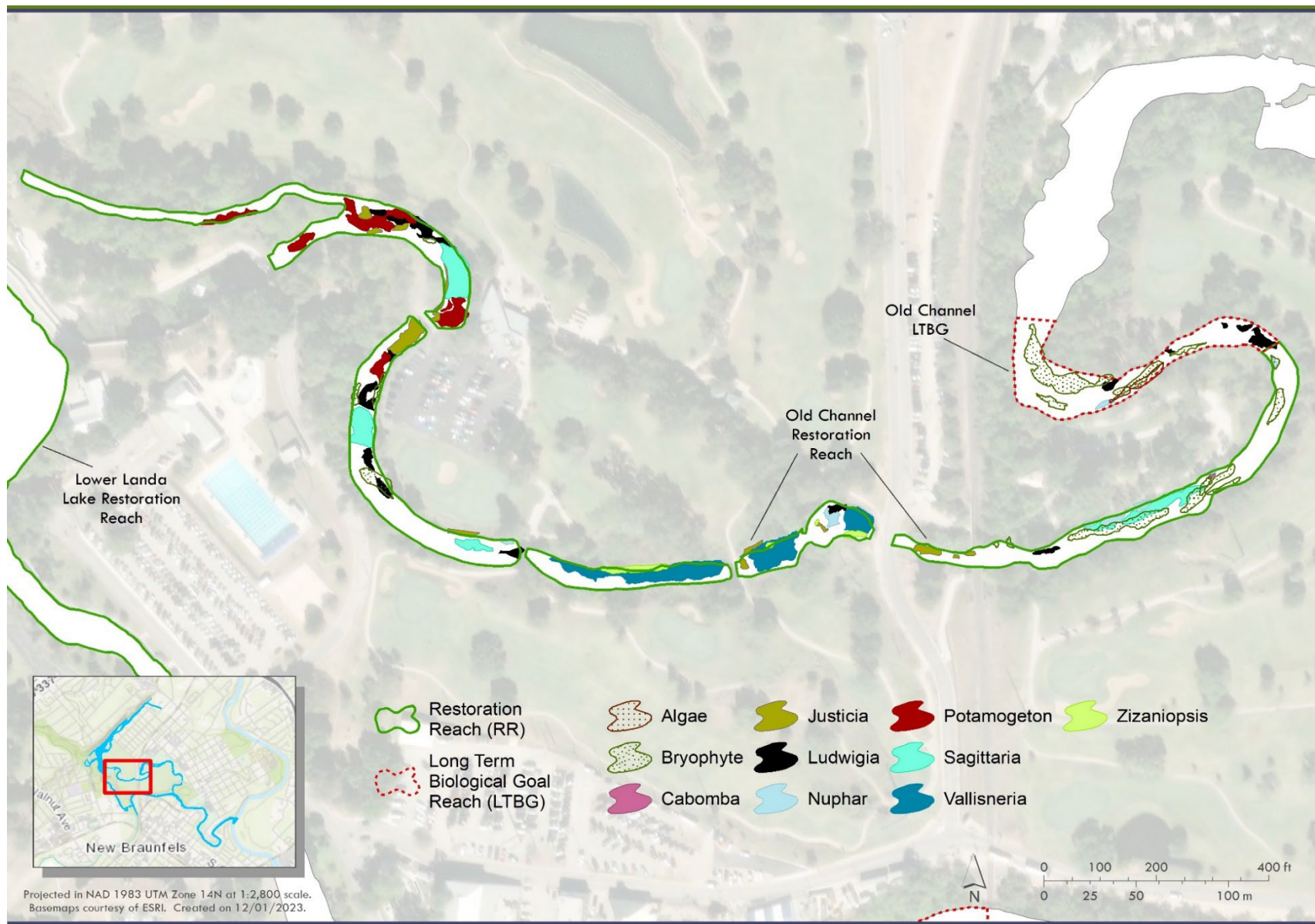


**Figure 5** Restored aquatic vegetation in the Old Channel in January 2023.



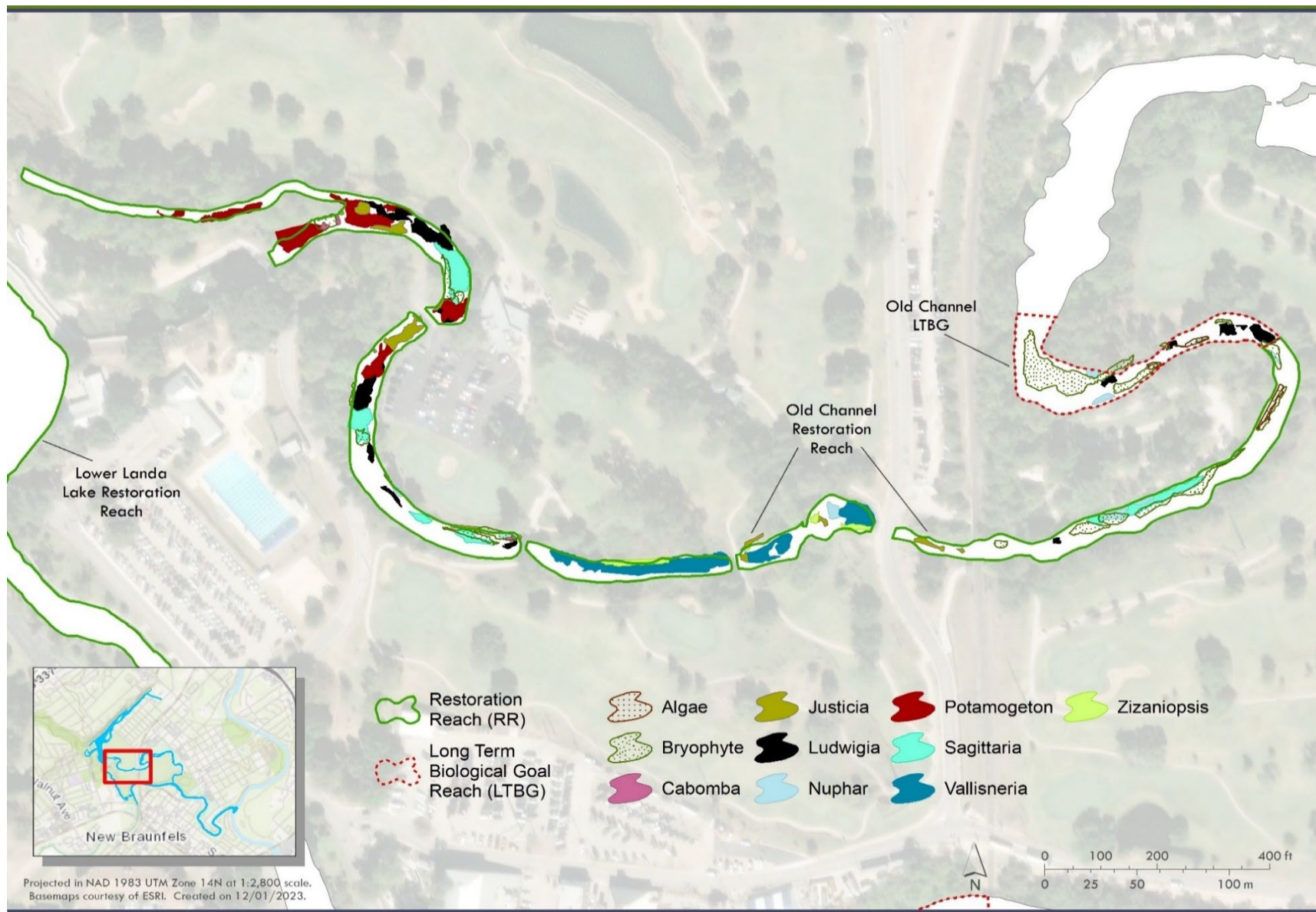


**Figure 6** Restored aquatic vegetation in the Old Channel in April 2023.



**Figure 7** Restored aquatic vegetation in the Old Channel in July 2023.





**Figure 8** Restored aquatic vegetation in the Old Channel in October 2023.

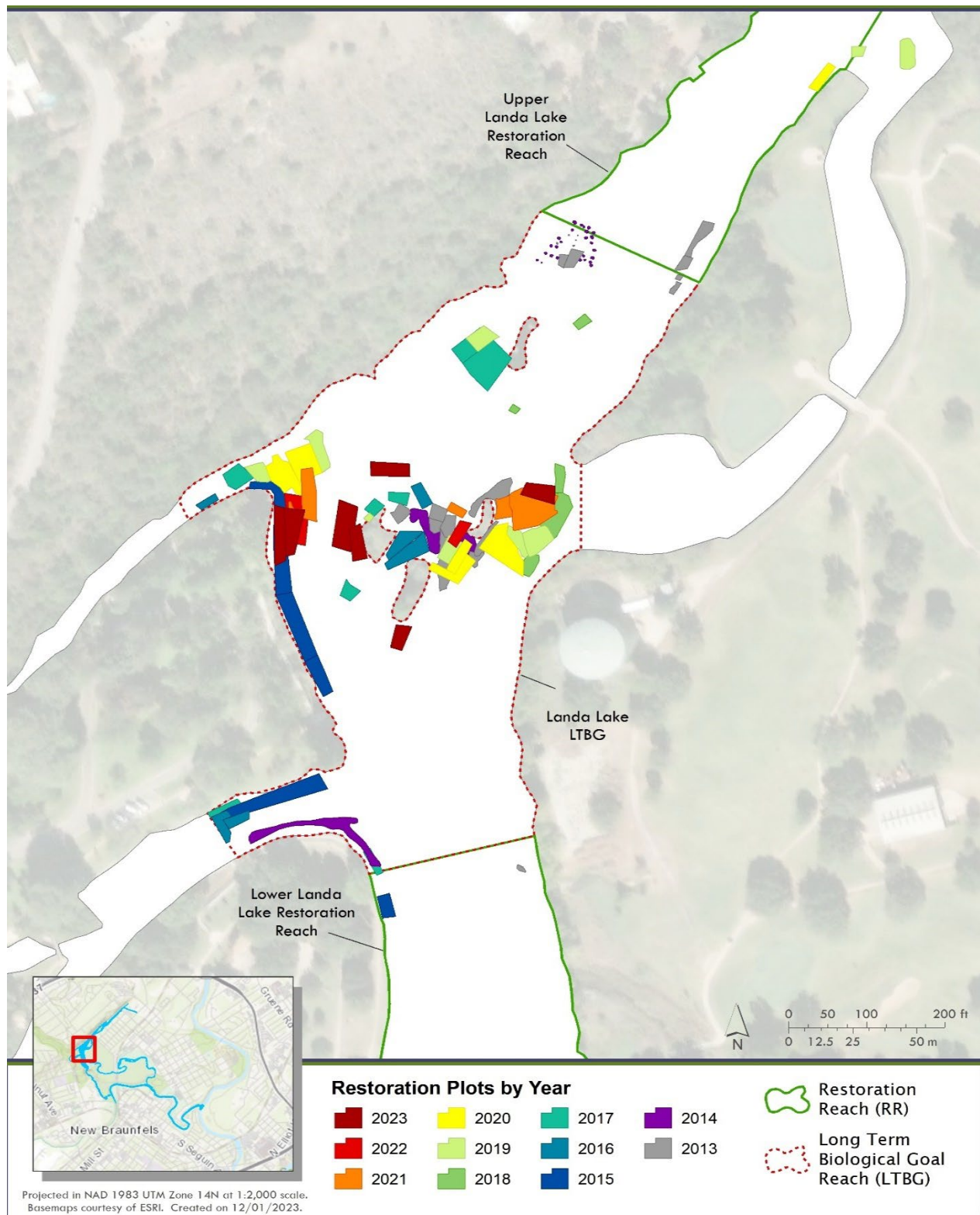
#### 4.4.2 Landa Lake Restoration Results

This year's plantings were limited to the Landa Lake LTBG Reach and resulted in a total of 1,020 Ludwigia, 4,300 Cabomba and 386 Potamogeton plants installed in the reach (**Table 4**). There were 7 new plots planted with a portion of plants installed as supplements to older plots. A combined area of 431 m<sup>2</sup> was planted in new restoration plots created from natural open areas within Vallisneria (**Figure 9, Appendix A**). Condition M limited the window for planting site preparation and large-scale plantings. The team was able to plant the majority of plants before Condition M was reached. Afterwards, regular trimming and supplemental sprigging of Ludwigia and Cabomba was the primary activity. Trimming is necessary to keep plants in a sprawling growth phase, which is especially beneficial during lower water levels. The trimmings were then planted by hand as sprigs. After July, activities in all the Landa Lake reaches were limited to gardening and maintenance. This included clearing vegetation mats, cleaning algae from newly planted plots and removing limbs and branches to prevent buildup of floating debris. Filamentous and epiphytic algae in Landa Lake was occasionally excessive and when problematic was flushed away by using hand-held SCUBA Scooters to the degree practical.

**Table 4** Planting dates and number of native specimens planted within new plots in Landa Lake LTBG. Shaded numbers indicate supplemental plantings in pre-existing plots.

Dates	Plot	Ludwigia	Cabomba	Potamogeton
1/2 3/16	23A		800	
1/4 4/12	23B		200	
1/11 2/6	23C		800	
1/2	23D	200		
1/4 1/9 1/10 1/13 2/6	23E		720	
4/12	23F		300	
8/19 9/14 10/16	23G	325	150	
6/8 6/14 6/15	23G			386
4/28 5/23 5/25	22A		900	
6/26	21B	300		
7/14	21A	195		
10/16	21C		430	
<b>Total</b>		<b>1,020</b>	<b>4,300</b>	<b>386</b>

Low flow events this year impacted Vallisneria growth with plants becoming shorter and thinner. Bare or sparse patches appeared where the flow was diverted away. Vallisneria in the main channels of current remained unaffected. The bare areas where Vallisneria died were locations targeted for Cabomba and Ludwigia sprigs. The Ludwigia in deeper areas, such as around Spring Run 3, remained healthy due



**Figure 9 Restoration plots in the Landa Lake LTBG Reach.**



to the incoming current and flow. In the past several years, the area around Spring Run 3 was targeted for *Ludwigia* plantings specifically because this area would provide ideal growing conditions, and subsequently prime Fountain Darter habitat, for the longest period of time during low flow events. Cabomba and Potamogeton were added to the general area this year. In shallower areas, such as around Three Islands, *Ludwigia* continually emerged into large surface mats or grew onto a mud bank as the water level receded (**Figure 10**). There were at least two significantly sized vegetated areas in Landa Lake which became terrestrial from August to October. During this time, Landa Lake was approximately two feet lower than normal. In October, water depths were measured in selected areas around Landa Lake to document how shallow some areas of Landa became. This map can be found in **Appendix B**. Cabomba did not seem impacted by reduced flows and flourished in all the new locations it was planted. It persevered and even expanded at its location around Pecan Island.

**Table 5** shows the coverages in square meters of selected species per reach during each mapping event. In the LTBG Reach, *Ludwigia* stayed above 1,000 m<sup>2</sup> until July when summer senescence caused biomass to be lost as the plants thinned out. *Ludwigia* coverage remained below 1,000 m<sup>2</sup> for the fall mapping event. Cabomba reached the highest coverage in Landa Lake since 2013, surpassing 1,000 m<sup>2</sup>. Cabomba thrived in the slower flows, slightly warmer water and reduced *Vallisneria* growth present over the past eight months. It expanded well in areas where *Vallisneria* receded and Cabomba was sprigged. *Vallisneria* coverage overall did not see a measured decrease but in specific locations, *Vallisneria* receded where velocity and water depth was reduced. Large open areas appeared within *Vallisneria* below and adjacent to the Three Islands area. This is where vegetation mats accumulated over several months. *Sagittaria* was seemingly less impacted by low flows. It remained healthy and dense throughout its distribution in the lake. Because *Sagittaria* can also grow as an emergent plant, it continued to expand along the eastern edge of Landa Lake into previously unvegetated areas. Bryophytes remained minimal in Landa Lake compared to historical patterns. Over the last three years bryophyte coverage has been trending downward and bryophytes are becoming uncommon even in their historically prime locations in Landa Lake.

In the Upper Landa Lake Restoration Reach, vegetation coverages shifted over the year. Bryophytes and benthic algae typically dominate this reach along with some established *Sagittaria*. Due to depth and cobble substrate, as well as persistent summer algae (*Spirogyra*), only specific locations of this reach are



**Figure 10** Emergent *Ludwigia* growing on exposed mud bank at the Three islands area of Landa Lake in August of 2023. This area is normally 10 to 12 inches in water depth.

suitable for restoration plantings. In 2023, filamentous and epiphytic algae were a nuisance, but Cabomba persisted well in this reach, even self-sprigging in new areas.

Cabomba located in the Lower Landa Lake Restoration Reach remained stable and even expanded to some degree intermixing with *Vallisneria* as that species thinned out. Floating vegetation mats were common in this reach through much of the year and tended to accrue around the boat house where water currents were minimal. Although these mats sometimes covered Cabomba stands, the plants persisted throughout the year.

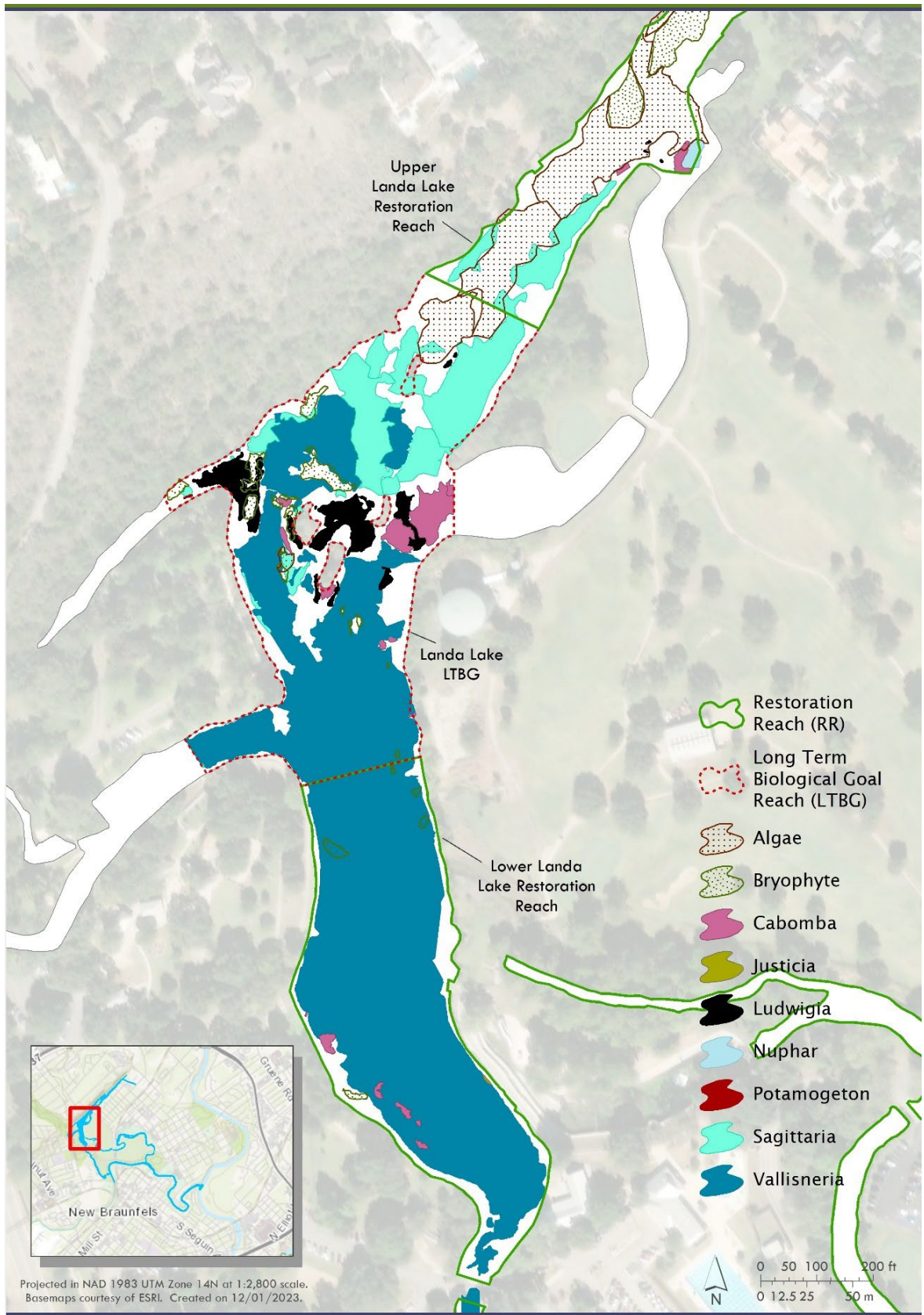
**Figures 11, 12, 13 and 14** show the mapped cover of aquatic vegetation in the Landa Lake LTBG and Upper and Lower Landa Restoration Reaches throughout 2023.



**Table 5**      **Seasonal cover (m<sup>2</sup>) of target restoration species in the Landa Lake LTBG and Restoration Reaches from GIS mapping from September 2022 to October 2023.**

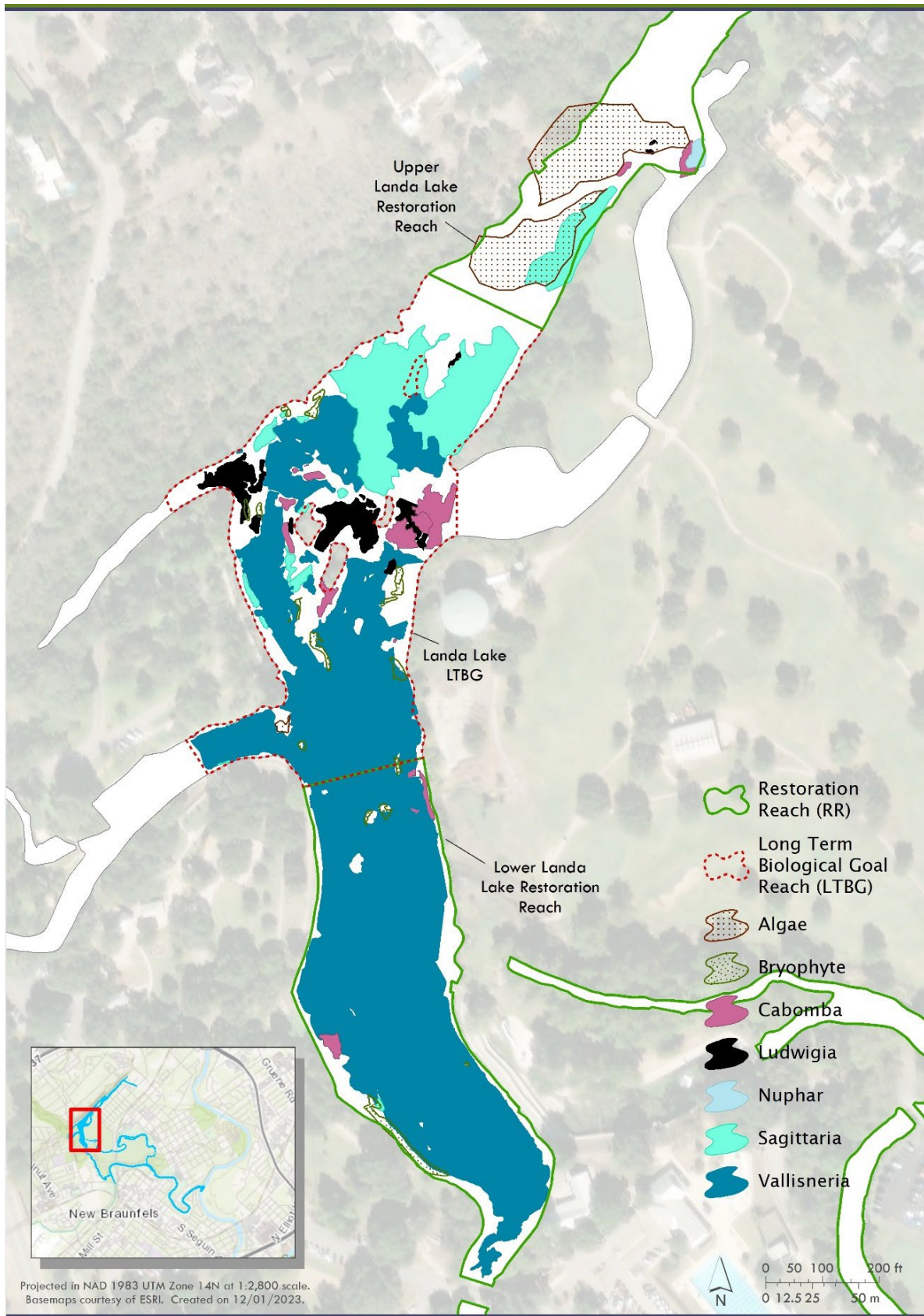
<b>Species</b>	<b>September 2022</b>	<b>Jan. 2023</b>	<b>April 2023</b>	<b>July 2023</b>	<b>Oct. 2023</b>
<b>Landa Lake LTBG Reach</b>					
Ludwigia	1,076	1,409	1,203	882	955
Sagittaria*	3,306	3,534	3,771	3,338	3,033
Cabomba*	512	616	749	1,032	1,005
Potamogeton	2	4	0	22	37
Vallisneria*	10,913	8,875	8,371	10,202	8,913
Bryophyte	192	523	265	22	103
algae	808	809	29	682	0
<b>Upper Landa Lake Restoration Reach</b>					
Ludwigia	0	6	10	20	7
Sagittaria	1,092	1,538	744	927	961
Cabomba	47	100	85	114	199
Bryophyte	937	870	0	0	233
<b>Lower Landa Lake Restoration Reach</b>					
Ludwigia	39	0	0	0	0
Sagittaria	20	16	14	35	77
Cabomba	104	107	217	276	409

\* These numbers combine naturally occurring and planted Sagittaria, Cabomba and Vallisneria in Landa Lake.

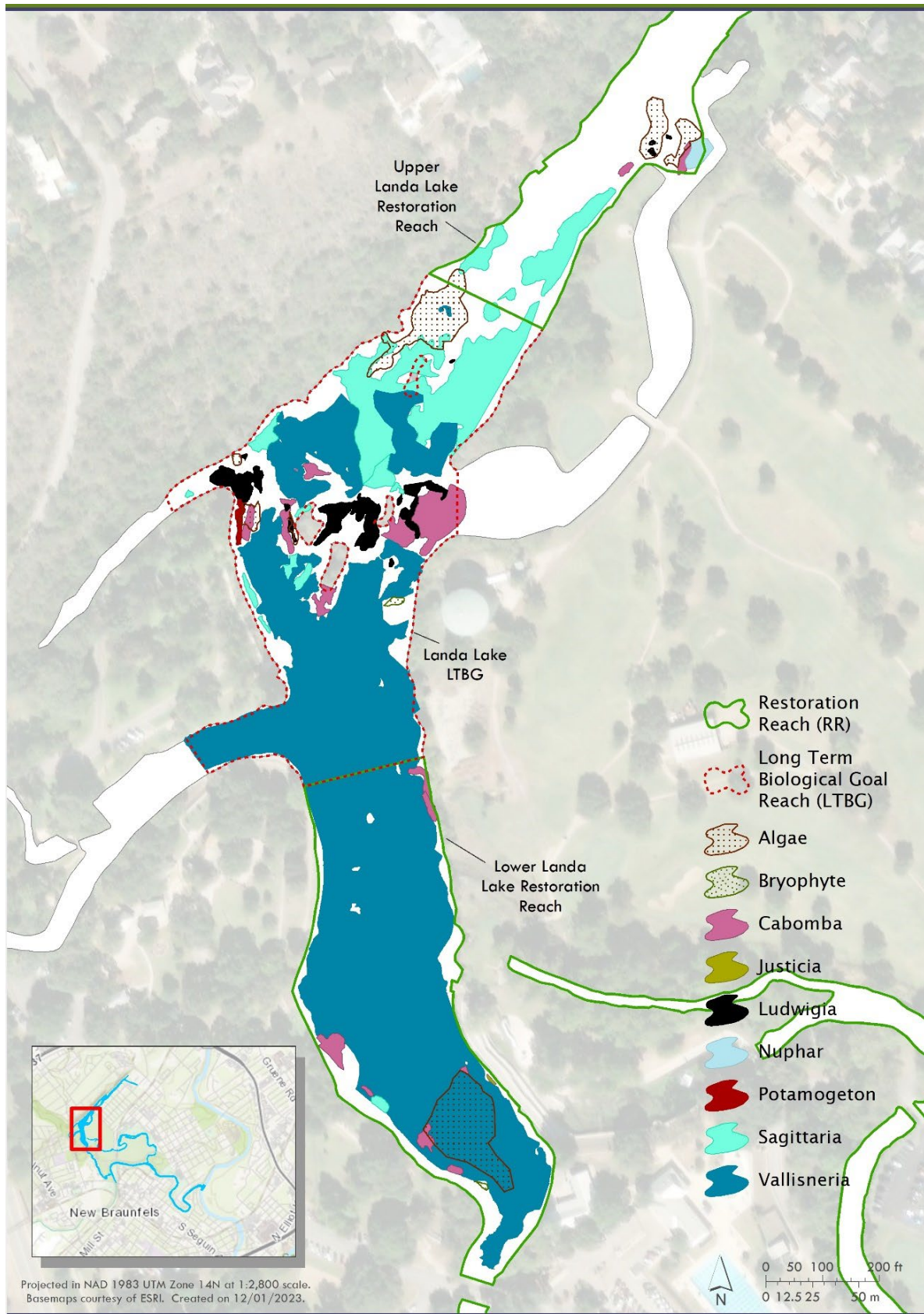


**Figure 11 Cover of aquatic vegetation in Landa Lake in January 2023**



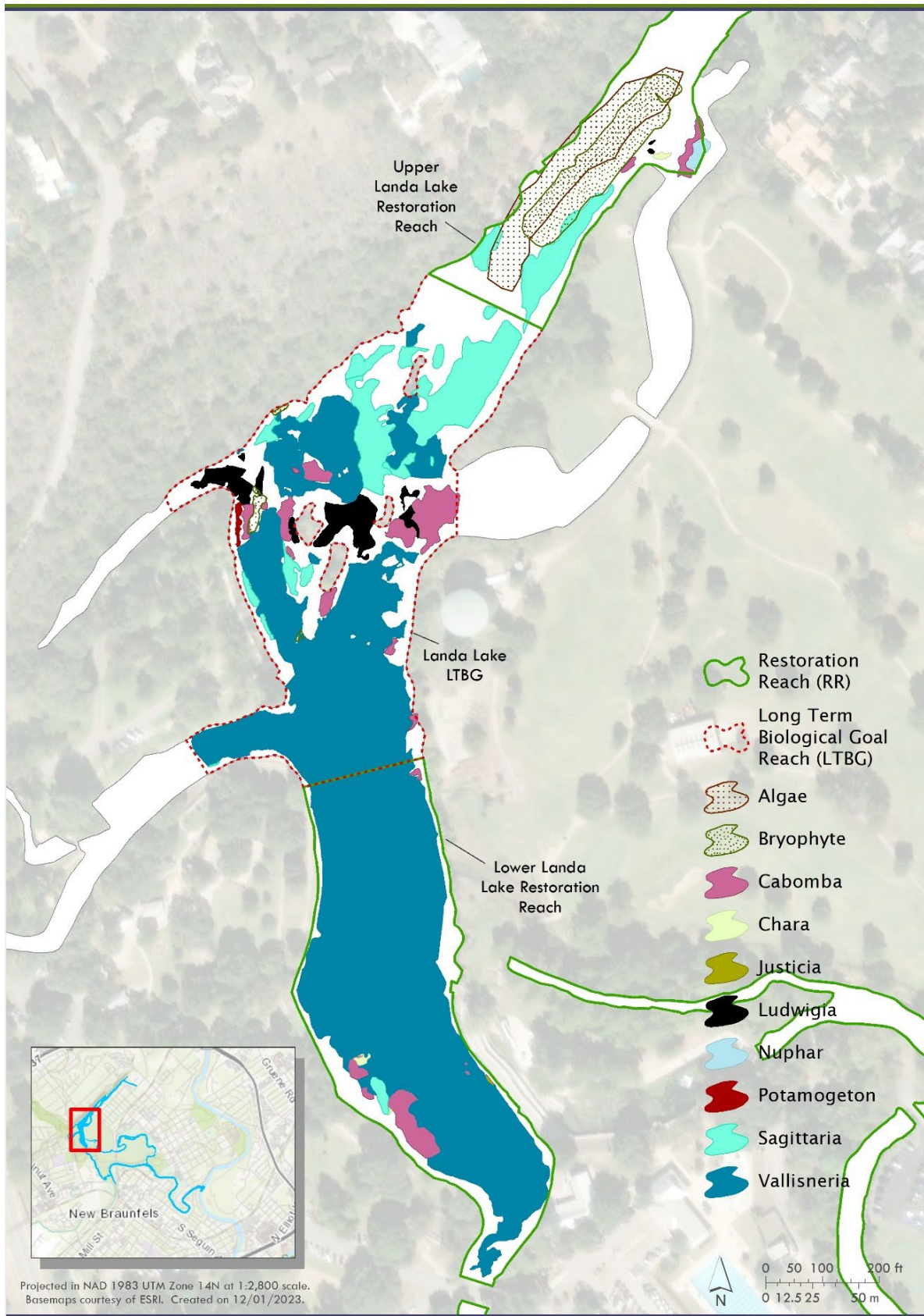


**Figure 12 Cover of aquatic vegetation in Landa Lake in April 2023.**



**Figure 13** Cover of aquatic vegetation in Landa Lake in July 2023.





**Figure 14 Cover of aquatic vegetation in Landa Lake in October 2023.**

#### 4.4.3 Upper Spring Run Restoration Results

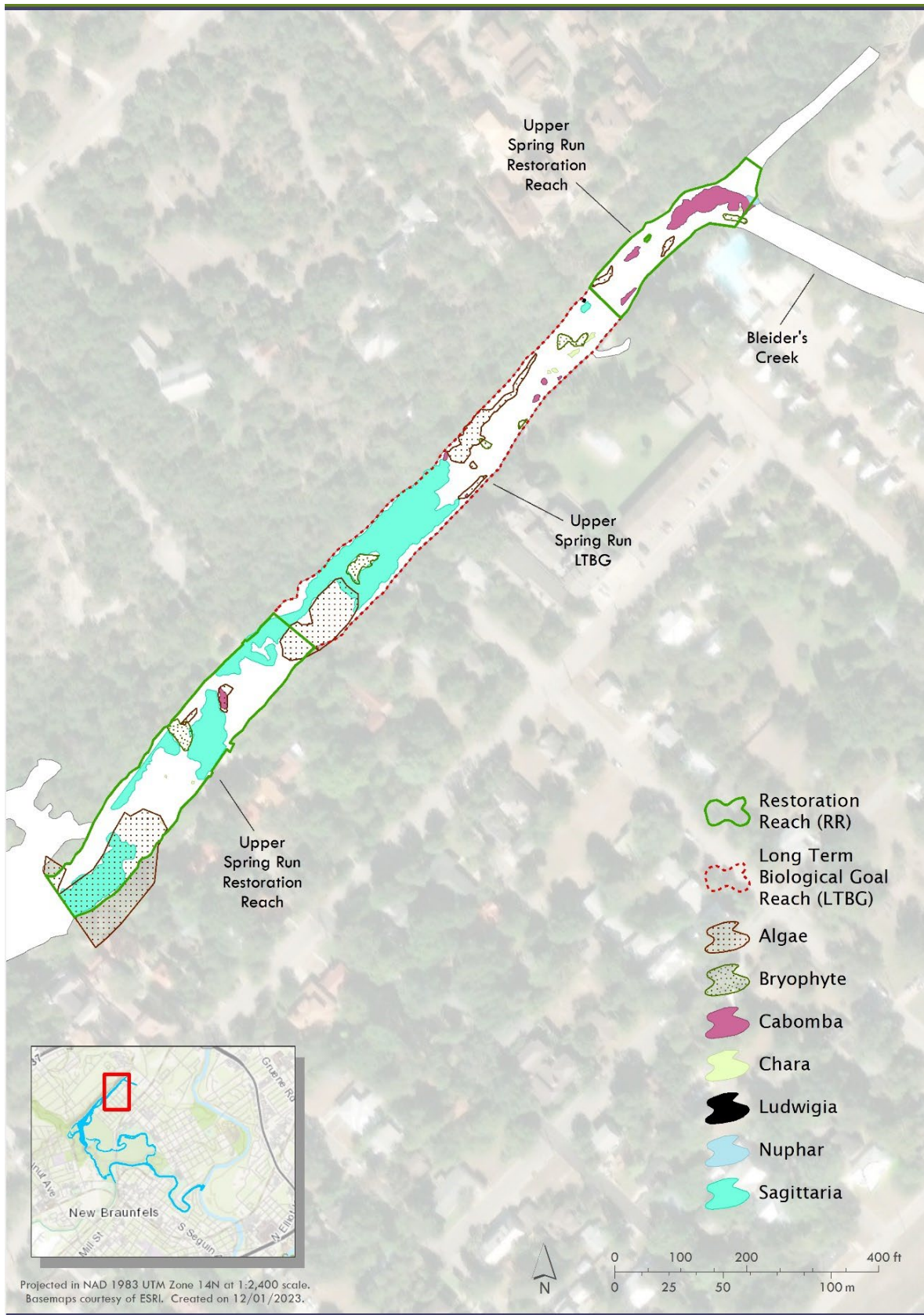
No active restoration plantings occurred in the Upper Spring Run Restoration Reach in 2023. As the drought persisted, the water level in this reach dropped significantly, such that *Sagittaria* in most of the reach began emerging. The emergent stems created catch points for floating algae and detritus. During multiple observations, large areas of Upper Spring Run were covered in floating algal mats and leaf debris and the water flow in this area diminished.

Over the course of 2023, algae and *Sagittaria* dominated Upper Spring Run reaches. The macroalga *Chara*, typically not found in this reach, became abundant. *Spirogyra* algae also dominated at times but waned during some mappings. As the year progressed, *Cabomba* coverage increased. While *Cabomba* is always present around Blieders Creek, it voluntarily expanded into the lower sections of the Upper Spring Run (Table 6). Figures 15, 16, 17 and 18 show the baseline, spring, low flow and fall maps of aquatic vegetation in the Upper Spring Run LTBG and Restoration Reaches.

**Table 6** Seasonal cover (m<sup>2</sup>) of target restoration species in the Upper Spring Run LTBG and Restoration Reaches from September 2022 to October 2023.

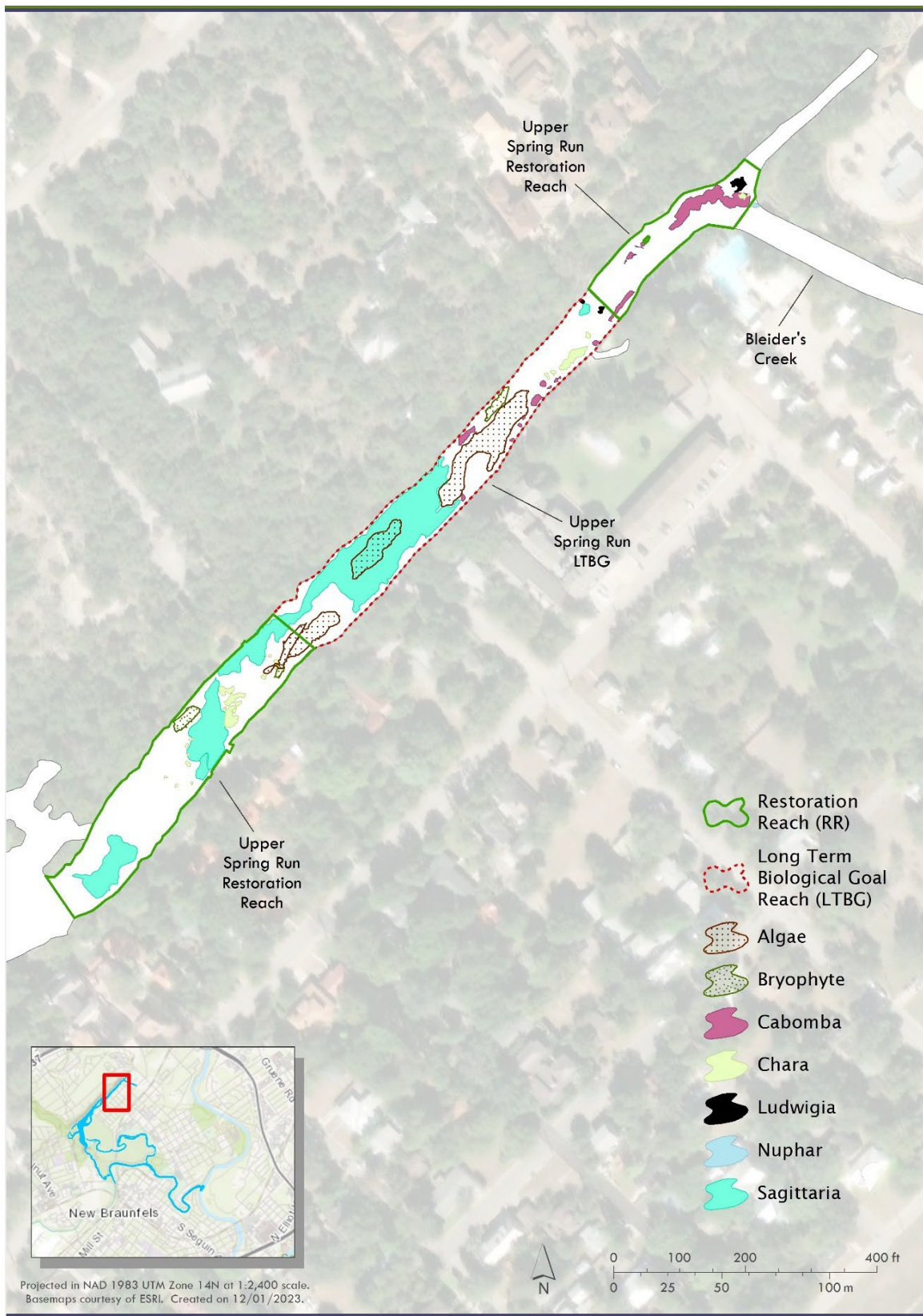
Species	September 2022	Jan. 2023	April 2023	July 2023	Oct. 2023
USR LTBG Reach					
Ludwigia	0	1	7	28	11
Sagittaria	1,625	1,264	1,490	1,510	1,185
Cabomba	27	18	60	67	113
Bryophyte	0	51	22	13	0
Algae	314	525	660	251	235
USR Restoration Reach					
Ludwigia	0	0	16	78	1
Sagittaria	1,152	1,108	835	1,308	853
Cabomba	217	325	223	220	333
Bryophyte	58	84	33	0	0
Algae	289	1,306	71	120	97



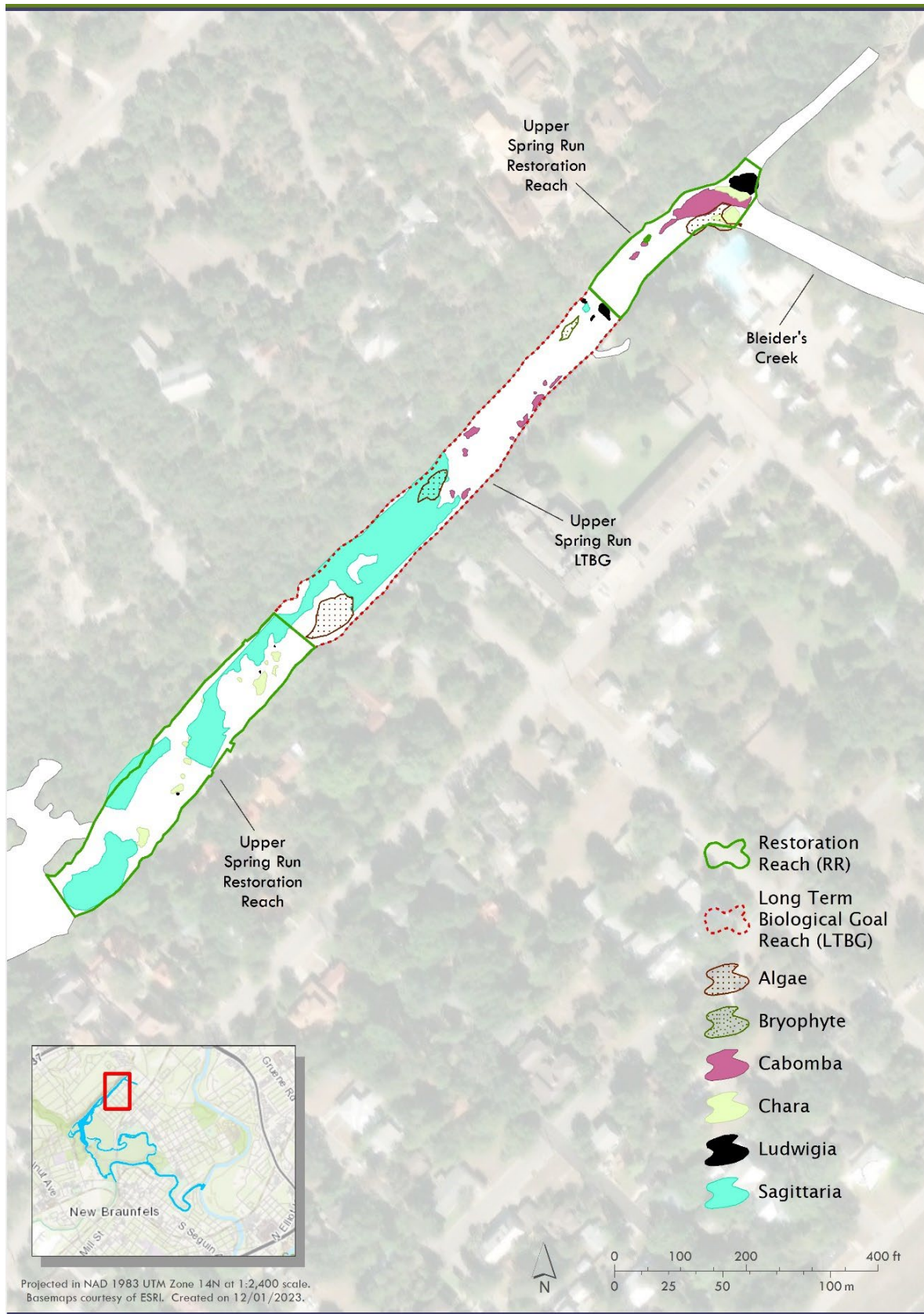


**Figure 15** Cover of aquatic vegetation in the USR reaches in January 2023.



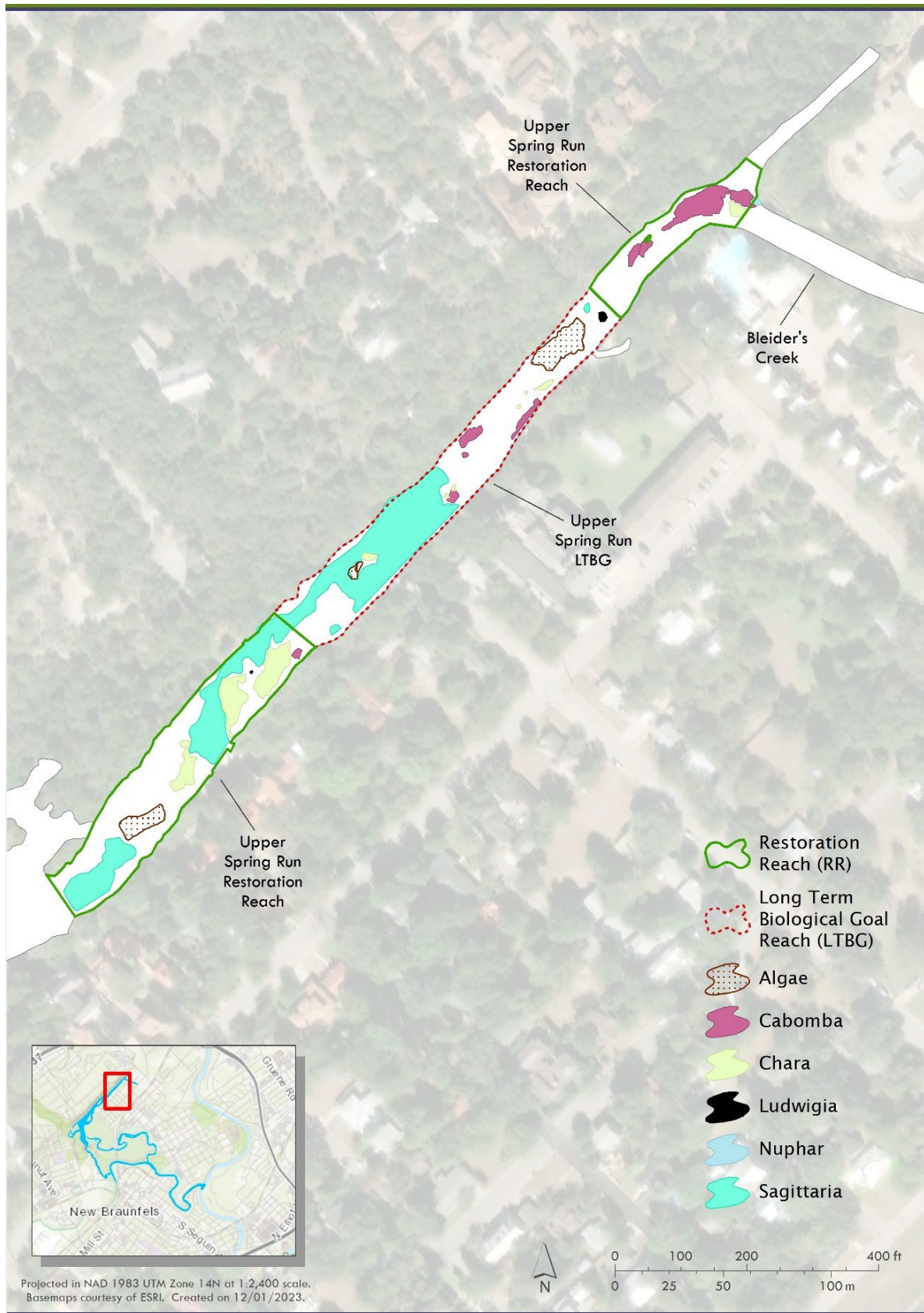


**Figure 16 Cover of aquatic vegetation in the USR reaches in April 2023.**



**Figure 17** Cover of aquatic vegetation in the USR reaches in July 2023.





**Figure 18** Cover of aquatic vegetation in the USR reaches in October 2023.

## 5 Restoration Summary

The purpose of aquatic vegetation restoration in the Comal River is to improve Fountain Darter habitat not only during times of normal flow, but to ensure usable habitat persists during droughts. As such, restoration efforts have been conducted with drought in mind. In 2023, continued drought conditions led to decreased discharge in the Comal springs, yet high-quality habitat consisting of *Ludwigia* and *Cabomba* persisted in Landa Lake and the Old Channel. The activation of Condition M of the HCP limited the timeframe for most restoration activities to just four months early in the year. Within those four months, the project team conducted a majority of the plantings in Landa Lake and the Old Channel so that for the rest of the year these plants could offer better habitat under poor conditions. The project team's overall methodology of regular gardening, trimming and algae removal ensures the native plants are healthy and persist through drought conditions to the best degree possible.

**Table 7** includes the annual cover changes per reach and highlights the current status of project goals. With some exceptions, goals are being met on an annual basis (square meters planted). Final goals for some species per their locations are presently exceeded. For other species or locations, actual coverages will vary from the goals depending on the growing conditions for the year among other factors. An important caveat to note regarding **Table 7** is that *Sagittaria* and *Vallisneria* are no longer planted in any reach as part of the current restoration regime but are still considered target species for habitat. Instead, these two species are allowed to expand on their own in areas where they were originally planted or where they already exist naturally. Currently, the project team has refrained from planting more *Sagittaria* in the Old Channel LTBG Reach to prevent competition with more desirable *Ludwigia* and *Cabomba*. Future strategies entail removing some *Sagittaria* and possibly *Potamogeton* from the Old Channel Restoration Reach to create increased planting space for *Ludwigia* and *Cabomba*. Goals for competitive species such as *Sagittaria*, *Potamogeton* and *Vallisneria* in certain reaches may require amendments based on observed results of previous years' restoration attempts and available on-site habitat conditions.

**Table 7 Summary of 2023 native aquatic vegetation restoration efforts in the Comal system.**

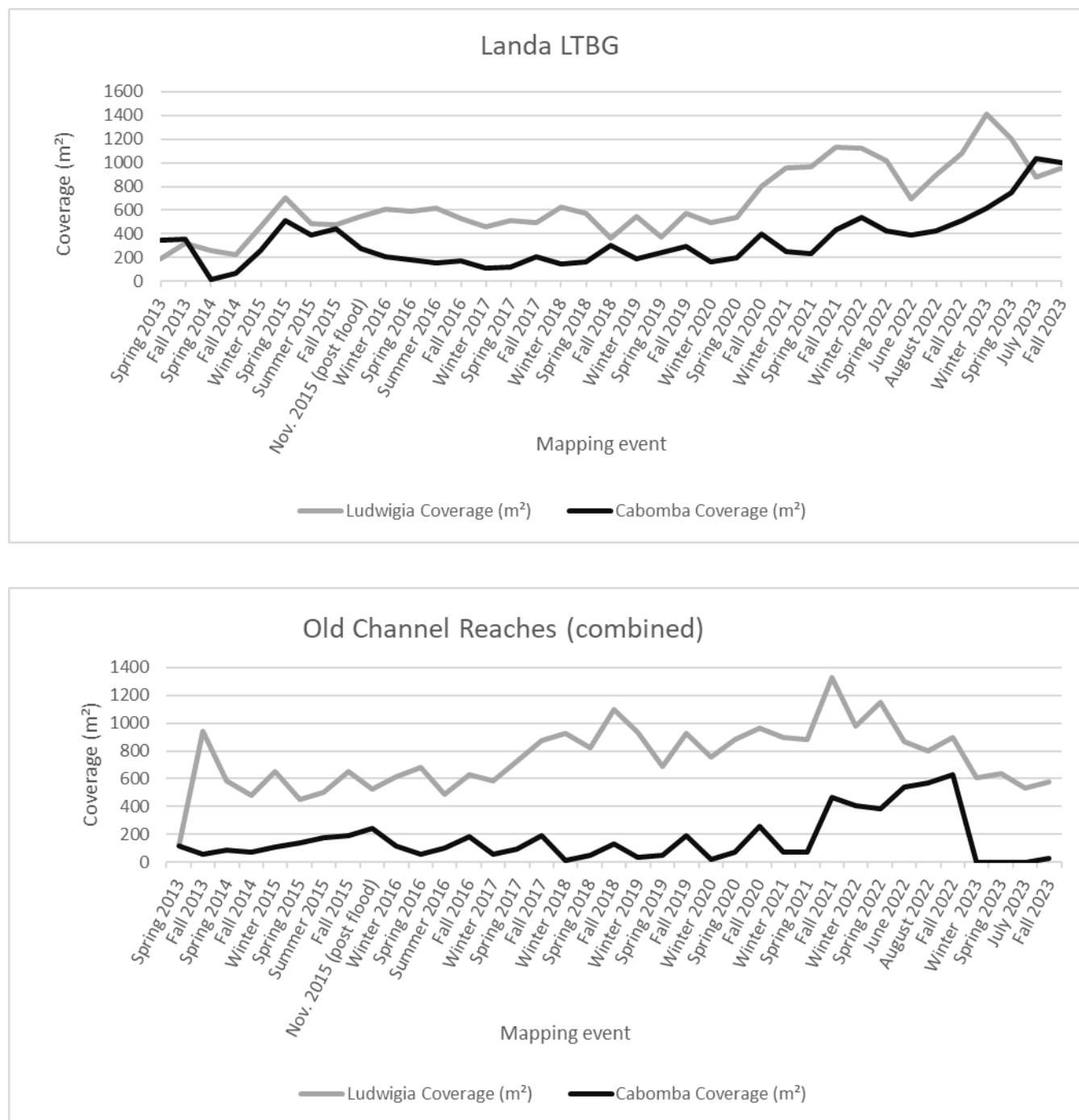
Reach	Aquatic Vegetation Species	Native Aquatic Vegetation Coverage (m²)				
		Fall 2022	Fall 2023	Gain / (Loss)	Total Planted Area (2023)	HCP Long-term Program Goal
LTBG Reaches						
Old Channel	Ludwigia	290	151	(139)	0	425
	Cabomba	495	0	(495)	0	180
	Sagittaria	0	0	0	0	450
Landa Lake	Ludwigia	1,076	955	(121)	72	900
	Cabomba	512	1005	493	495	500
	Vallisneria	10,913	8,913	(2,000)	0	12,500
	Potamogeton	2	37	35	98	25
Upper Spring Run	Ludwigia	0	11	11	0	25
	Cabomba	27	113	86	0	25
	Sagittaria	1,625	1,185	(440)	0	850
Restoration Reaches						
Landa Lake Upper	Ludwigia	0	7	7	0	25
	Cabomba	47	199	152	0	250
	Sagittaria	1,092	961	(131)	0	250
Landa Lake Lower	Ludwigia	39	0	(39)	0	50
	Cabomba	104	409	305	0	125
	Sagittaria	20	77	(75)	0	100
Old Channel	Ludwigia	605	428	(177)	0	850
	Cabomba	132	29	(103)	0	200
	Sagittaria	785	726	(59)	0	750
	Vallisneria	847	812	(35)	0	750
	Potamogeton	540	878	338	0	100

N/D – No data available

**Figure 19** tracks the long-term changes in Ludwigia and Cabomba coverage since restoration began in 2013. These graphs highlight the inherent fluctuation in coverage of these two species. There are several explanations for this pattern. First, senescence is a natural process in which plants undergo a reduction in biomass as a seasonal reaction (reduced daylight, cooler water temperatures) or a life cycle change (maturation, post-blooming). Senescence can also be a response to changes in growing conditions. A strong senescence period was seen in June 2023 when low flow conditions set in. Inevitably, this caused a reduction in plant biomass. Sometimes the plants habituate to the changing conditions and may recover, while at other times, senescence leads to death as the plant has entered its final life stage and lacks the energy to recover. Second, loss of cover can be caused by competition and later complete exclusion due to the expansion of other, more aggressive native species, as previously detailed. These



two factors together commonly lead to a reduction in cover that is equal to or higher than the amount planted,



**Figure 19** The ten-year trend for coverages for Ludwigia and Cabomba in the Landa Lake LTBG Reach (top) and the combined reaches of the Old Channel (bottom).

making consistent year to year coverage difficult. In Landa Lake, the trend in coverage for Ludwigia and Cabomba is generally increasing. The alteration in methodology toward creating larger contiguous

patches of *Ludwigia* and *Cabomba* is anticipated to reduce losses and improve sustainability. Expectations are that the coverage trend will show a more consistent pattern over the next year and annual gains will be greater than achieved in the past. In the Old Channel, the trend for *Ludwigia* and *Cabomba* turned downward after several years of success. This was mostly a direct result of impacts in the Old Channel LTBG Reach where these species never naturally recovered over the course of the year. Importantly, a large and constant level of bryophytes were maintained in the Old Channel LTBG reach over the course of 2023, which created quality Fountain Darter habitat conditions. These recent changes continue to highlight the need for active management and improvements. The native aquatic plant restoration and maintenance activities conducted in 2023 continue to enhance the aquatic ecosystem of the Comal River and provide valuable lessons. Additionally, the continued decline and subsequent rarity in non-native aquatic vegetation in the Comal system has been an incredible success story in this ongoing habitat restoration project.

**Appendix A** includes maps of 2023 plots overlaid with the fall 2023 vegetation distribution to gauge planting area versus resulting plant coverage discussed in the body of the report.

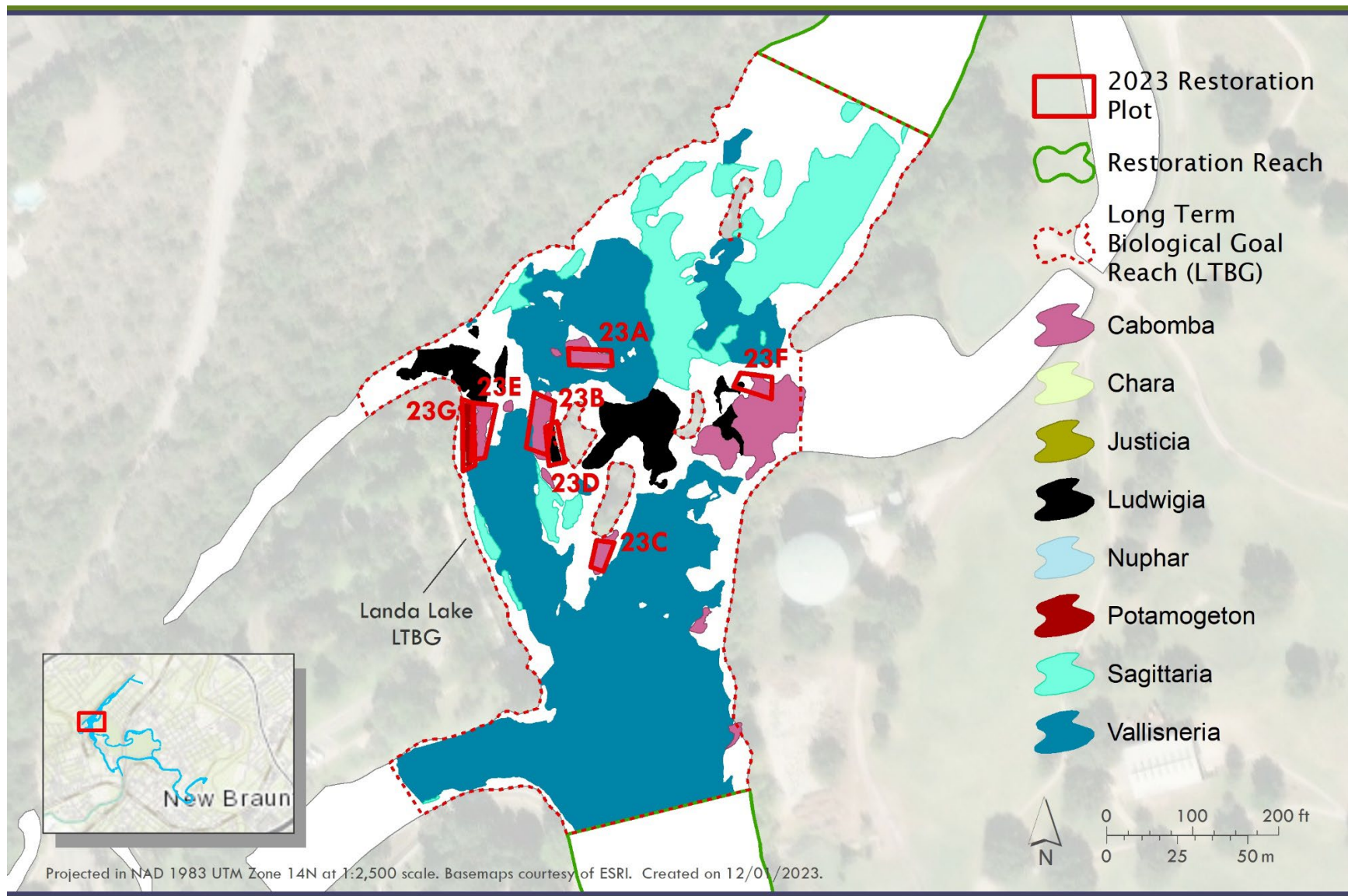
**Appendix B** includes the map of measured water depths in Landa Lake.

## 6 References

- BIO-WEST 2013a. 2013 Restoration Plan for Aquatic Vegetation in Landa Lake and Old Channel Reach. May 13, 2013. Prepared for City of New Braunfels, TX, 72pp.
- BIO-WEST 2013b. 2013 Aquatic Vegetation Restoration in Landa Lake and the Old Channel of the Comal River. November 20, 2013 Prepared for City of New Braunfels, TX 80pp.
- BIO-WEST 2013c. 2013 Edwards Aquifer Authority Habitat Conservation Plan(HCP) Applied Research. November 20, 2013 Prepared for Edwards Aquifer Authority, San Antonio, TX 110pp.
- BIO-WEST 2014. 2014 Aquatic Vegetation Restoration in Landa Lake and the Old Channel of the Comal River. November 20, 2014 Prepared for City of New Braunfels, TX 68pp.
- BIO-WEST 2015. 2015 Aquatic Vegetation Restoration in Landa Lake and the Old Channel of the Comal River. November 20, 2015 Prepared for City of New Braunfels, TX 72pp.
- BIO-WEST 2016. 2016 Aquatic Vegetation Restoration in Landa Lake and the Old Channel of the Comal River. November 10, 2016 Prepared for City of New Braunfels, TX 72pp.
- (USGS) United States Geological Survey. 2019. National Water Information System: Web Interface for USGS Gage No. 08169000 for the period January 1, 2019 to October 1, 2019.  
[<http://waterdata.usgs.gov>]

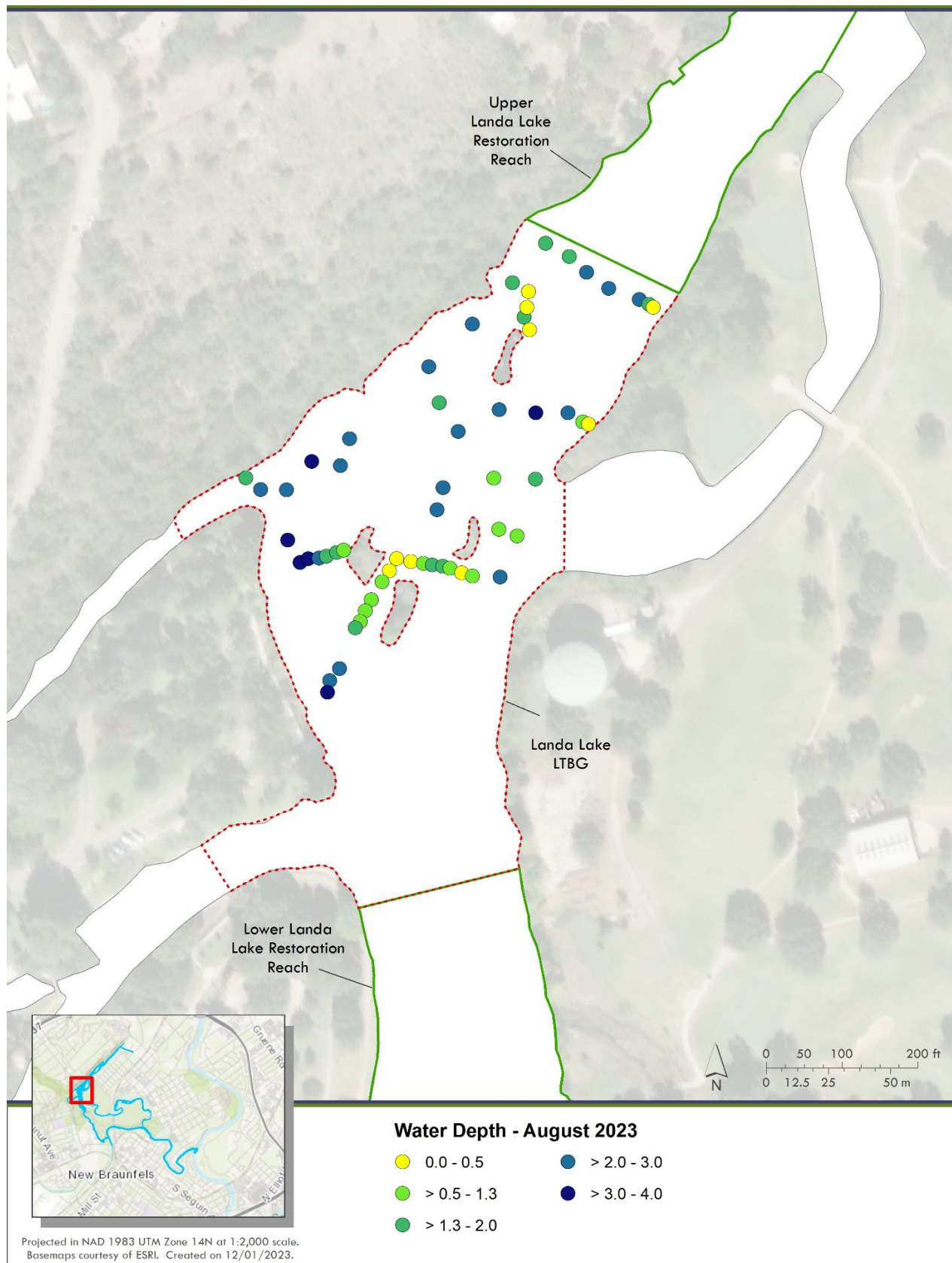
# 7 Appendix A





**Figure A1** Plots planted in Landa Lake LTBG in 2023 and their resulting vegetation cover in fall 2023.

# 8 Appendix B



**Figure B1 Measured water depths (ft) in Landa Lake in September.**



## Appendix H2 | **Dissolved Oxygen Monitoring**





## MEMORANDUM

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TO: Phillip Quast (City of New Braunfels)  
FROM: Ed Oborny (BIO-WEST)  
DATE: **November 21, 2023**  
SUBJECT: BIO-WEST Dissolved Oxygen Management Plan 2023 Activities

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### EXECUTIVE SUMMARY

This memorandum summarizes BIO-WEST's 2023 activities associated with the City of New Braunfels Dissolved Oxygen Management Plan (Plan). BIO-WEST's involvement in 2023 centered around the Low spring flow conditions triggered monitoring as summarized below from annual scope of work:

- Deploy near-continuous DO monitoring sensors at six strategic locations within the Comal River system upon the onset of low-flow conditions (<100cfs) at Comal Springs. Monitoring shall be focused in monitoring locations within prime Fountain Darter habitat in Landa Lake.
- Maintain and service DO monitoring sensors.
- Off-load DO data from sensors on a routine basis.
- Inform City of New Braunfels staff of low-dissolved oxygen conditions as measured by sensors or other method and recommend mitigation actions based on the Landa Lake Dissolved Oxygen Management Plan.
- Evaluate and analyze collected DO data. Assess the linkage between DO concentrations as measured at the six sensors and observed Fountain Darter data collected as part of the Edwards Aquifer Habitat Conservation Plan (EAHCP) Biological Monitoring Program;

In summary, compilation and analysis of 2023 data collection revealed that dissolved oxygen (DO) suitable for Fountain Darters was typically maintained in key Fountain Darter areas consistent with both the EAA near-continuous sonde monitoring in Comal Springs as well as the EAHCP biological monitoring data collected during drop net sampling. Although periodic observances of DO below 3.0 mg/L were observed, these were typically only exhibited for short durations of time mostly associated with early morning hours. Fountain Darters have been and were again collected in 2023 in all these areas through the EAHCP biological monitoring program drop net and dip net sampling. Our conclusion based on the additional DO sampling performed in 2023 is that no revisions to the existing City of New Braunfels Dissolved Oxygen Management Plan regarding the Low spring flow conditions triggered monitoring is recommended at this time. The project team supports the DO Low spring flow monitoring Work Plan components in place and recommends the City of New Braunfels continue implementation in 2024.

### 2023 FIELD SAMPLING

Six strategic locations were again used in 2023 based on previous years sampling and continuously monitored when total system discharge declined below 100 cfs during the summer and early fall months. The six sites include one in the Upper Spring Run, four in Landa Lake, and one in the Old Channel (**Figure 1**).



**Figure 1.** Six Dissolved Oxygen continuous monitoring Low flow sites in the Comal System.

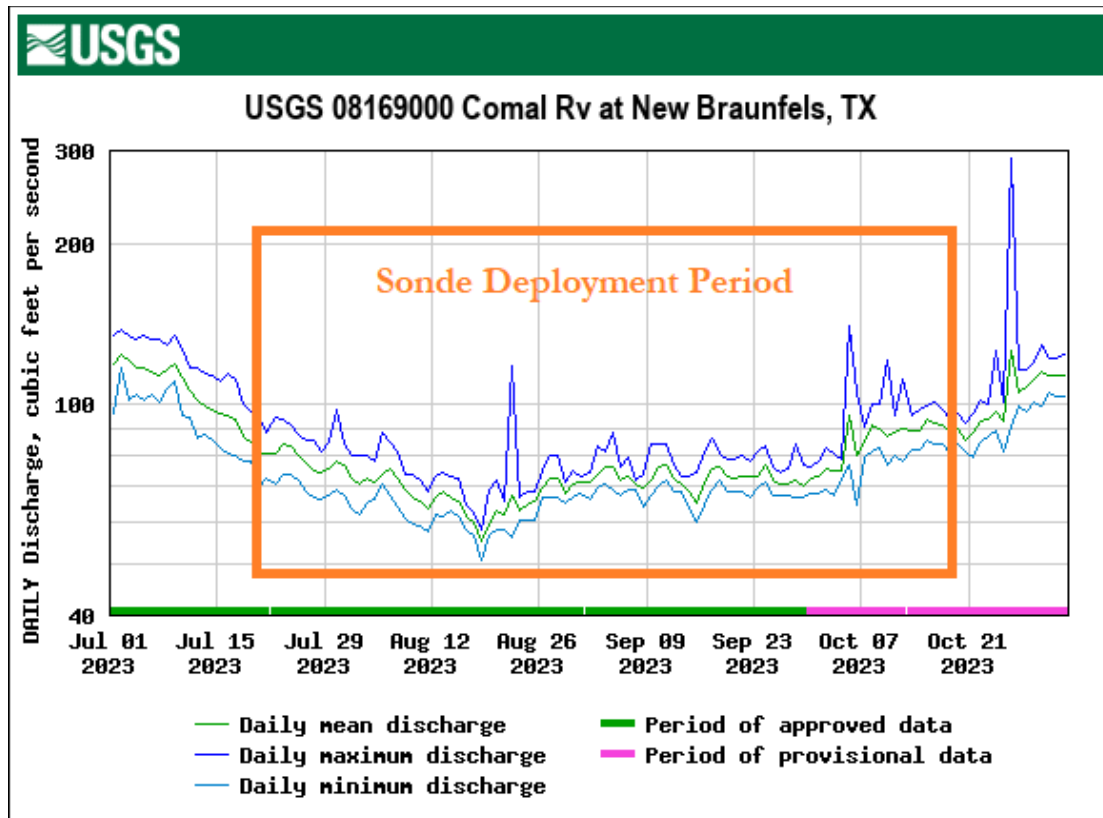


With coordination and approval from the City of New Braunfels, BIO-WEST deployed all six MiniDOT sondes on July 21, 2023. Figure 2 shows a MiniDOT sonde deployed at the Upper Spring Run site. Solid anchoring devices were again used in 2023. The sensors were purposely installed just off the bottom to examine the portion of water column utilized directly by the Fountain Darter.



**Figure 2.** MiniDOT sonde deployed at Upper Spring Run Study Site.

During the July 21<sup>st</sup> through October 17<sup>th</sup> deployment period, MiniDOTs were downloaded multiple times and cleaned approximately once per week in between downloads. Data for the Spring Run 3 location was only available through August 11<sup>th</sup>, as it was unfortunately stolen the following week. The remaining five sondes were downloaded, retrieved, cleaned and stored in late-October following an increase in Comal Total System Discharge to 100 cfs (**Figure 3**).



**Figure 3.** USGS recorded Total System Discharge at Comal River at the New Braunfels USGS gage over the MiniDOT deployment.

Table 1 highlights some summary statistics for both the DO and water temperature data collected over the summer deployment period. The extremely hot summer caused rapid and extensive fouling on the MiniDOT's this year, often times causing drift within a few days. This required more frequent cleaning this year compared to what was necessary in 2022. This also resulted in the need to cull the data set to exclude obvious DO drift. Overall, the average DO concentration across all sites was approximately 6.7 mg/L, with wide diel swings in DO being experienced at all sites (excepting Spring Run 3). These swings resulted in short periods of DO being less than 3 mg/L at all sites in 2023. As expected, these lower excursions were typically only exhibited for short durations of time mostly associated with early morning hours.





**Table 1.** Dissolved Oxygen and Water Temperature data collected from July 21 to October 17, 2023 at six monitoring sites in the Comal System using MiniDOT sondes.

Site	Dissolved Oxygen (mg/L)		Water Temperature (°C)	
	Minimum	Average	Average	Maximum
Upper Spring Run	< 3.0	8.16	24.97	30.57
Landa Lake (MUPPTs)	< 3.0	6.34	24.32	27.67
Landa Lake (Three Islands)	< 3.0	6.56	24.58	28.11
Landa Lake (Spring Run 3)	< 3.0	5.14	23.71	24.43
Landa Lake (Pecan Island)	< 3.0	6.72	24.68	29.66
Old Channel	< 3.0	7.30	24.87	29.89

Overall, the DO average levels reported in 2023 were similar to summer time conditions observed historically through EAHCP biological monitoring. The stations closest to the main spring openings (both major spring runs and lake upwellings) maintained a more consistent water temperature and less daily fluctuation of DO. The sensor in the Old Channel exhibited typical and consistent diel fluctuations in DO and water temperature. The site in the slowest moving water (Upper Spring Run) exhibited the warmest water temperatures and corresponding lowest DO values. The lower than average flow conditions, coupled with the extreme ambient temperatures in August and September 2023 did result in slightly higher water temperatures than experienced historically and last summer. These increased water temperatures and reduced flow contributed to the high amount of biofouling experienced on the probes this year.

Although periodic observances of DO below 3.0 mg/L were observed in the MiniDOT data at the majority of stations, these values were typically reported only for short durations of time. These occurrences were mostly associated with early morning hours and/or the onset of biofouling on the probes. It is important to reiterate that Fountain Darters have been routinely collected over the years at each of these locations via drop net and dip net, and were again documented in 2023 in these areas through the EAHCP biological monitoring program. Overall, there was no cause for concern with respect to DO at any of the six study sites during the summer and early fall 2023 deployment period. As of this memorandum (November 2023), Total System Discharge is above 100 cfs and Fountain Darter habitat in both Landa Lake and the Old Channel is being maintained.

Our conclusion based on the additional Low flow triggered DO sampling performed in 2023 is that no revisions to the existing City of New Braunfels Dissolved Oxygen Management Plan regarding the Low spring flow conditions triggered monitoring is recommended at this time. The project team supports the DO Low spring flow monitoring Work Plan components in place and recommends the City of New Braunfels continue implementation in 2024.



## Appendix H3 | **Control of Harmful Non-Native Animal Species**

### CoNB Control of Harmful Non-Native Animal Species (EAHCP § 5.2.5)

The CONB continued to implement a non-native fish and animal species management program focused on the removal of tilapia (*Oreochromis sp.*), nutria (*Myocastor coypus*) and vermiculated sailfin catfish (family Loricariidae). In 2023, divers utilized primarily polespears and spearguns for capture of non-native fish species and baited box traps to capture nutria. Tilapia were targeted primarily in the main body of Landa Lake, near the confluence of Blieders Creek/ Landa Lake and in the Upper Spring Run while sailfin catfish were targeted primarily in the downstream portion of Landa Lake. Efforts to capture nutria were focused primarily around Landa Lake, in the Upper Spring Run area and along Blieders Creek. **Table 1** summarizes the number of non-native fish and animal species removed from the Comal River system in 2023.

**Table 1.** Summary of Non-Native Fish & Animal Species Removal (January – December 2023)

Species	Number Removed	Biomass (lbs.)	Average Biomass (lbs./individual)
Vermiculated Sailfin Catfish	68	151.24	2.2
Tilapia	766	1971.46	2.6
Nutria	20	131.4	6.6
Goldfish	7	7.46	1.1



## Appendix H4 | **Gill Parasite Monitoring in the Comal River System**





BIO-WEST, Inc.  
1405 United Drive, Suite 111  
San Marcos, Texas 78666

## MEMORANDUM

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TO: **Phillip Quast, City of New Braunfels**

FROM: BIO-WEST, Inc.

DATE: **November 21, 2023**

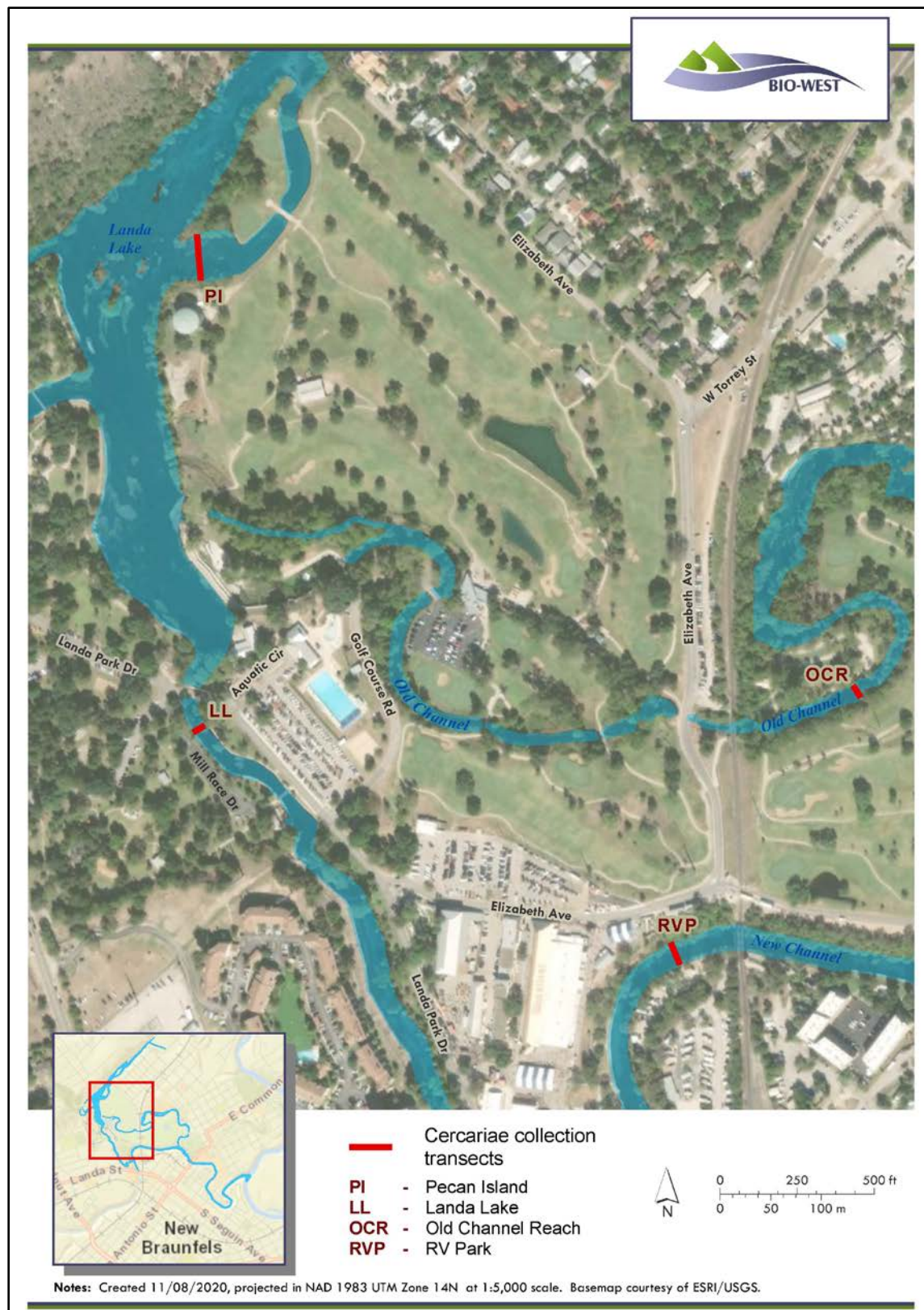
SUBJECT: **2023 Gill Parasite Monitoring in the Comal River**

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### Introduction

To benefit populations of the federally-endangered Fountain Darter *Etheostoma fonticola*, the Edwards Aquifer Habitat Conservation Plan (EAHCP) has conducted studies aimed at monitoring and reducing concentrations of the non-native gill parasite *Centrocestus formosanus* in the Comal River. Studies initially included data collection targeted at identifying the distribution, abundance, and density of the free-swimming cercariae of *C. formosanus* as well as its host snail, *Melanoides tuberculatus*. They also included studies to document current prevalence of *C. formosanus* in host snails and Fountain Darters, and pilot studies to evaluate host snail removal as a means of potentially reducing *C. formosanus* concentrations. Additionally, during this time period, data were also collected on the abundance and density of the cercariae of another exotic trematode parasite, *Haplorchis pumilio*, which has the potential to negatively impact Fountain Darter populations. Lastly, repeat monitoring was implemented to track host snail (2013–2018) and parasite cercariae concentration (2013–2023) through time.

From 2014 through 2018, parasite cercariae monitoring was conducted three times per year (Winter, Spring, and Summer seasons) at three transects (Landa Lake [LL], Old Channel Reach [OCR], and RV Park [RVP]; **Figure 1**). In 2019, at the request of the City of New Braunfels and Edwards Aquifer Authority, monitoring efforts were decreased to one event per year, and a fourth sampling transect was added at Pecan Island (PI) due to concerns of potentially high parasite concentrations at this location (**Figure 1**). Since 2019, BIO-WEST biologists have conducted a single summer-season parasite monitoring event at these four transects in the Comal River system. In 2023, this data collection took place on August 16–17, and included quantification of cercariae densities for both *C. formosanus* and *H. pumilio* at each transect. These data were combined with previously collected data from 2014–2022 and the full dataset was analyzed with updated statistical techniques to examine the relationship between multiple predictor variables (discharge, year, season, and site) and parasite concentrations. Details of the methods utilized, a summary of the results and subsequent analyses, a discussion on the utility of this information, and recommendations for further research and monitoring are provided below.



**Figure 1.** Map of cercariae collection transects in the Comal River system.

## Methods

### *Data Collection*

At each transect, 5-liter (L) water samples were collected from six points evenly distributed throughout the water column both vertically and horizontally. Three evenly spaced sampling stations were established across the stream channel, perpendicular to flow. At each station, two 5-L samples were collected, one at 60% stream depth, and one approximately 5 centimeters (cm) below the water surface, totaling six samples per site. Cercariae were collected using a modified live-well pump attached to an incremental wading rod which pumped water through clear acrylic tubing to collection buckets. At time of collection, each water sample was immediately treated with 5 milliliters (ml) of formaldehyde to kill all parasite cercariae. Each sample was then filtered using a specialized filtration device consisting of three progressively finer nylon filters, with the final filter having pores of 30 microns ( $\mu\text{m}$ ). After filtration of each sample, the 30- $\mu\text{m}$  filter containing cercariae was removed from the filtration device and placed in a Petri dish. Each sample was then stained with a Rose Bengal solution and fixed with 10% formalin, at which point the Petri dish was closed and sealed with Parafilm for storage. After fixation and staining, the samples were then observed using high-power microscopy (40–100 $\times$  magnification) and all cercariae were identified to species and enumerated in the BIO-WEST laboratory.

### *Data Analysis*

Spatiotemporal trends in cercariae density of both species were summarized and compared by calculating mean ( $\pm\text{SE}$ ) cercariae/L for each site per season and year. Random forest regression models were used to examine relationships between river discharge and density of *C. formosanus* and *H. pumilio* cercariae in the water column. Random forest regression is a type of ensemble decision tree model that generates a large number of trees via bootstrapping that are combined to make predictions. These types of models are advantageous for assessing ecological data, due to their ability to depict nonlinear trends and better generalize to new data (Breiman 2001; Prasad et al. 2006).

For all sampling events, discharge values (cfs) specific to each site were taken or calculated from USGS gaging stations on the Comal River (USGS gages 08168913, 08168932, 08169000) at 10:00 am on the day of collection. Specifically, discharge data for LL and PI were taken from the Comal River New Channel gage (08168932), data for OCR were taken from the Comal River Old Channel gage (08168913), and data for the RVP site were calculated as the difference of the total system gage (08169000) and Old Channel gage (08168913) to account for potential streamflow contributions from Dry Comal Creek. Discharges were then standardized by median discharge ( $\text{discharge}(x)/Q50$ ) for the study duration to make observations comparable between sites. In addition to standardized discharge, year was included as an additional continuous variable to assess temporal trends. Season and site were used as categorical predictors to account for unexplained spatiotemporal variation in cercariae densities.

Random Forest models were fit using 500 trees and tuned to maximize predictive performance (Breiman 2002). Statistics calculated to assess each model's performance were based on out-of-sample predictions and included mean of squared residuals, percent variation explained, and

correlation between observed and predicted cercariae densities. Percent decrease in mean squared error (MSE) was also calculated for each predictor variable, which represents the magnitude of feature influence relative to prediction error (Breiman 2002). Lastly, partial dependence plots are provided to display cercariae density trends as a function of standardized discharge and year. All analyses were conducted using R (4.1.1) packages ‘randomForest’ (Liaw 2022), ‘pdp’ (Greenwell 2022), and ‘ggplot2’ (Wickham 2023).

## Results

In 24 individual five-liter samples collected in 2023, 40 total *C. formosanus* and 49 *H. pumilio* cercariae were detected, resulting in an overall system wide mean ( $\pm$ SE) of 0.33 ( $\pm$ 0.08) and 0.41 ( $\pm$ 0.08) cercariae/L, respectively (**Table 1**). Overall means represent a slight decrease in densities since 2022, but were still higher than 2021 densities. Among sites, highest mean density of *C. formosanus* occurred at LL (0.63  $\pm$ 0.21 cercariae/L) and RVP (0.47  $\pm$ 0.12 cercariae/L). Mean density of *H. pumilio* was also greatest at RVP (0.80  $\pm$ 0.13 cercariae/L) and LL (0.57  $\pm$ 0.10 cercariae/L). Densities from 2022 to 2023 decreased or were equal at all sites except PI, though mean density at PI remained low and its magnitude of change was minimal relative to previous years for *C. formosanus* (0.03 to 0.07 cercariae/L) and *H. pumilio* (0.00 to 0.03 cercariae/L) (**Table 1**).

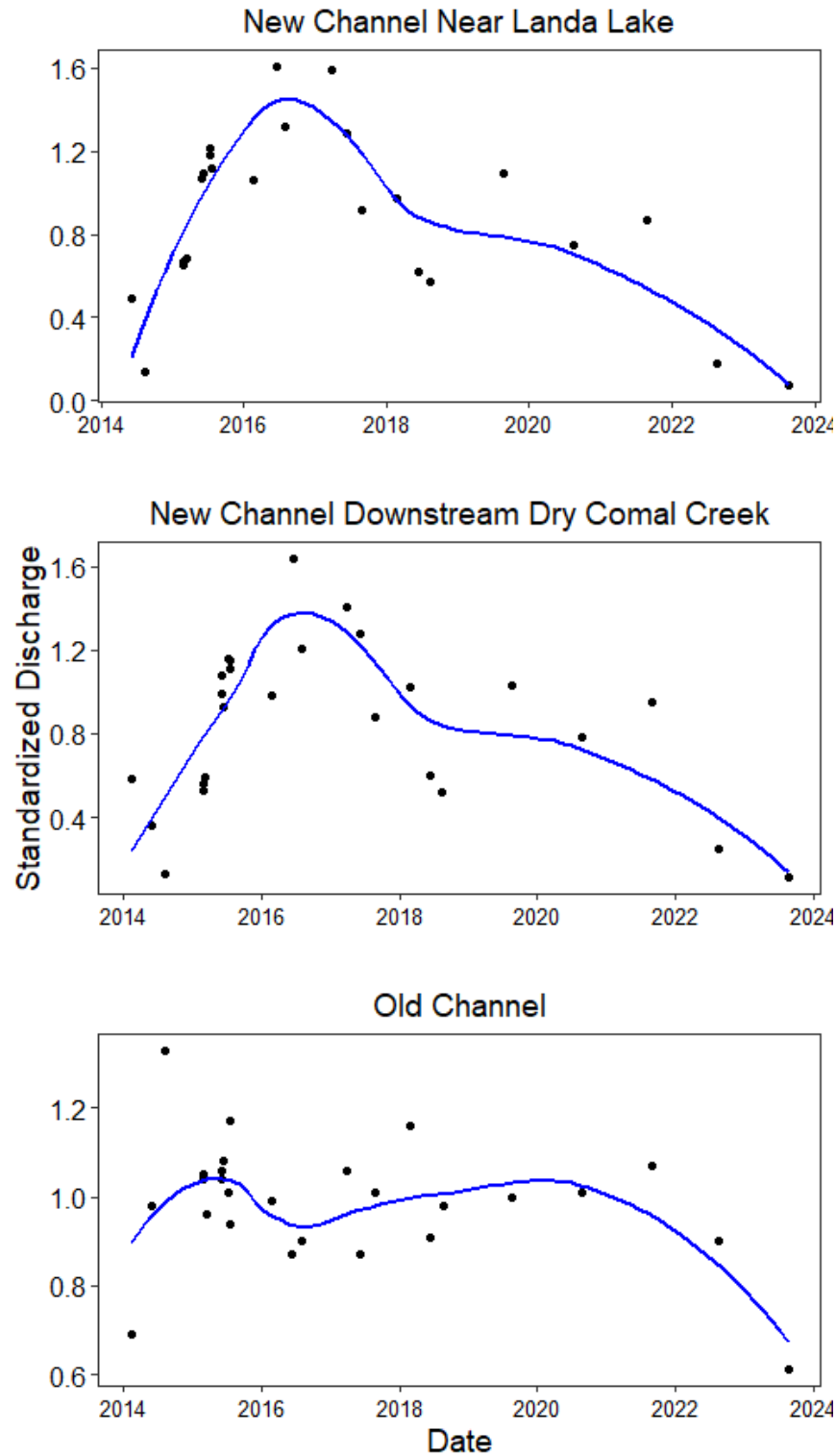
Random Forest Models were fit based on 492 observations in PI (n = 30), LL (n = 150), OCR (n = 156) and RVP (n = 156). Temporal trends in standardized discharge throughout the duration of cercariae monitoring were similar in the New Channel near Landa Lake and downstream of Dry Comal Creek, increasing from 2014 (~0.14) to 2017 (~1.50) and decreasing from 2017 to 2023 (~0.09). In the Old Channel, standardized discharge was also lower in 2014 (~0.70 in winter), but remained stable from 2015 to 2022, displaying slight to moderate variation from Q50, followed by a decline in 2023 (0.61) (**Figure 2**). Both models performed well with correlations between observed and predicted values  $\geq$ 0.70, though model correlation and percent variation explained was much higher for *C. formosanus* (0.92 and 84.19%, respectively) than *H. pumilio* (0.70 and 48.73%, respectively) (**Table 2**).

Based on percent increase in MSE, year (77.24%) and standardized discharge (47.74%) were the most influential predictors of *C. formosanus* density. Standardized discharge (43.93%) and site (40.94%) were most influential for predicting *H. pumilio* density and were shown to be more important compared to year (23.11%) (**Figure 3**). Partial dependence plots visualizing relationships between parasite density and standardized discharge displayed a nonlinear relationship for both species and showed that density sharply decreased with increasing standardized discharge from about 0.10 to 0.80 units. The partial dependence plots of *C. formosanus* annual trends show that density has steadily decreased from 2014 to 2023. In contrast, trends in *H. pumilio* density display a decrease in density from 2014 to 2017, followed by an increase from 2021 to 2023 (**Figure 4**).



**Table 1.** Mean cercariae/liter ( $\pm$ SE) collected during parasite monitoring events from 2014-2023.

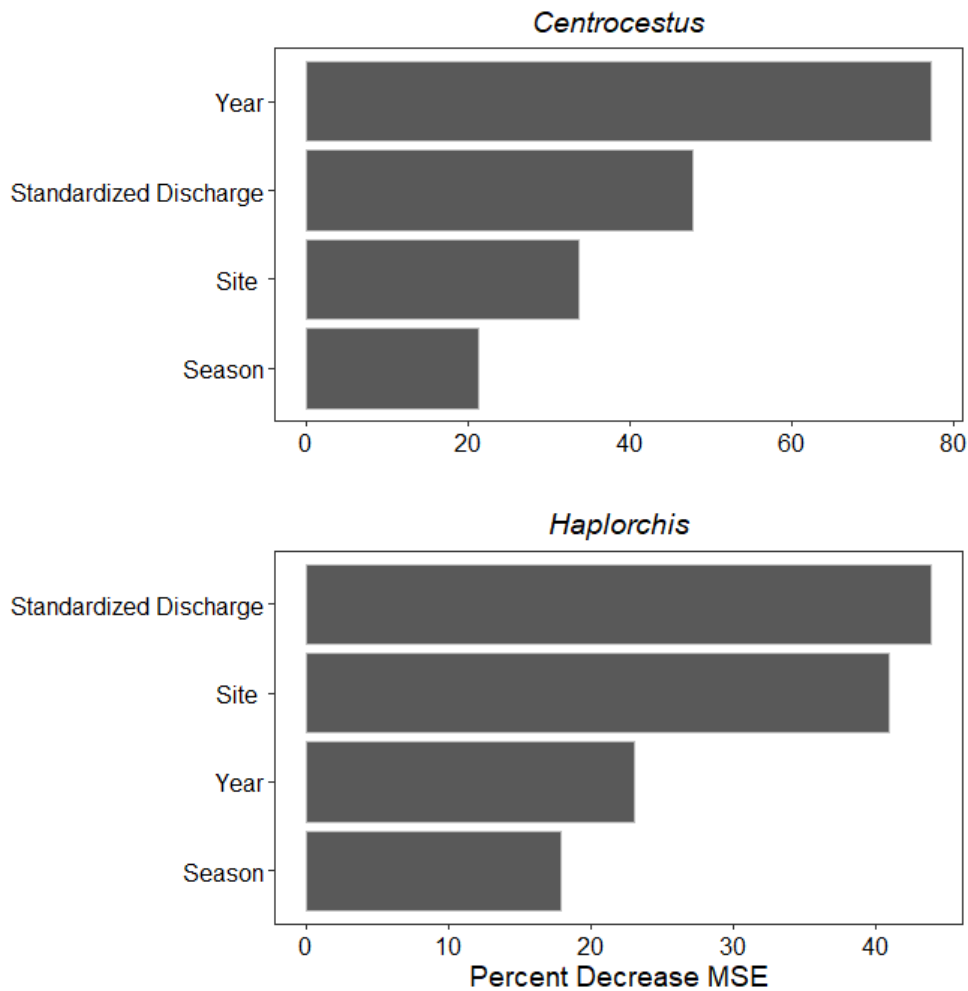
<i>C. formosanus</i>						<i>H. pumilio</i>					
Transect	Year	Season			OVERALL	Transect	Year	Season			OVERALL
		Winter	Spring	Summer				Winter	Spring	Summer	
<b>LL</b>						<b>LL</b>					
	2014	4.4 ( $\pm$ 0.4)	6.1 ( $\pm$ 0.5)	13.3 ( $\pm$ 0.6)	<b>7.9 (<math>\pm</math>1.0)</b>		2014	0.2 ( $\pm$ 0.09)	0.3 ( $\pm$ 0.08)	0.9 ( $\pm$ 0.24)	<b>0.5 (<math>\pm</math>0.11)</b>
	2015	2.6 ( $\pm$ 0.3)	2.6 ( $\pm$ 0.3)	3.4 ( $\pm$ 0.3)	<b>2.9 (<math>\pm</math>0.2)</b>		2015	0.5 ( $\pm$ 0.09)	0.3 ( $\pm$ 0.06)	0.2 ( $\pm$ 0.03)	<b>0.3 (<math>\pm</math>0.04)</b>
	2016	0.8 ( $\pm$ 0.9)	2.3 ( $\pm$ 0.8)	1.9 ( $\pm$ 0.8)	<b>1.6 (<math>\pm</math>2.2)</b>		2016	0.03 ( $\pm$ 0.03)	0.3 ( $\pm$ 0.08)	0.2 ( $\pm$ 0.08)	<b>0.2 (<math>\pm</math>0.04)</b>
	2017	1.3 ( $\pm$ 0.1)	1.4 ( $\pm$ 0.3)	1.0 ( $\pm$ 0.2)	<b>1.2 (<math>\pm</math>0.1)</b>		2017	0.06 ( $\pm$ 0.04)	0.03 ( $\pm$ 0.03)	0.03 ( $\pm$ 0.03)	<b>0.04 (<math>\pm</math>0.02)</b>
	2018	0.8 ( $\pm$ 0.1)	1.5 ( $\pm$ 0.2)	1.6 ( $\pm$ 0.4)	<b>1.3 (<math>\pm</math>0.2)</b>		2018	0.1 ( $\pm$ 0.07)	0.1 ( $\pm$ 0.04)	0.1 ( $\pm$ 0.04)	<b>0.1 (<math>\pm</math>0.03)</b>
	2019			0.4 ( $\pm$ 0.1)			2019			0.0 ( $\pm$ 0.0)	
	2020			0.3 ( $\pm$ 0.1)			2020			0.03 ( $\pm$ 0.03)	
	2021			0.2 ( $\pm$ 0.07)			2021			0.07 ( $\pm$ 0.04)	
	2022			0.63 ( $\pm$ 0.06)			2022			1.03 ( $\pm$ 0.09)	
	2023			0.63 ( $\pm$ 0.21)			2023			0.57 ( $\pm$ 0.10)	
<b>OCR</b>						<b>OCR</b>					
	2014	0.4 ( $\pm$ 0.1)	1.0 ( $\pm$ 0.2)	2.0 ( $\pm$ 0.3)	<b>1.1 (<math>\pm</math>0.2)</b>		2014	0.1 ( $\pm$ 0.04)	0.1 ( $\pm$ 0.07)	0.2 ( $\pm$ 0.09)	<b>0.1 (<math>\pm</math>0.04)</b>
	2015	1.4 ( $\pm$ 0.2)	1.9 ( $\pm$ 0.2)	2.4 ( $\pm$ 0.2)	<b>1.9 (<math>\pm</math>0.1)</b>		2015	0.2 ( $\pm$ 0.06)	0.3 ( $\pm$ 0.07)	0.1 ( $\pm$ 0.03)	<b>0.2 (<math>\pm</math>0.03)</b>
	2016	2.0 ( $\pm$ 1.1)	1.2 ( $\pm$ 0.9)	1.8 ( $\pm$ 1.2)	<b>1.7 (<math>\pm</math>1.1)</b>		2016	0.1 ( $\pm$ 0.07)	0.1 ( $\pm$ 0.07)	0.1 ( $\pm$ 0.07)	<b>0.1 (<math>\pm</math>0.04)</b>
	2017	0.7 ( $\pm$ 0.1)	0.6 ( $\pm$ 0.2)	0.5 ( $\pm$ 0.1)	<b>0.6 (<math>\pm</math>0.1)</b>		2017	0.0 ( $\pm$ 0.0)	0.0 ( $\pm$ 0.0)	0.0 ( $\pm$ 0.0)	<b>0.0 (<math>\pm</math>0.0)</b>
	2018	0.6 ( $\pm$ 0.1)	0.3 ( $\pm$ 0.1)	0.2 ( $\pm$ 0.1)	<b>0.4 (<math>\pm</math>0.1)</b>		2018	0.0 ( $\pm$ 0.0)	0.0 ( $\pm$ 0.0)	0.03 ( $\pm$ 0.03)	<b>0.01 (<math>\pm</math>0.01)</b>
	2019			0.4 ( $\pm$ 0.1)			2019			0.2 ( $\pm$ 0.06)	
	2020			0.4 ( $\pm$ 0.1)			2020			0.2 ( $\pm$ 0.1)	
	2021			0.1 ( $\pm$ 0.04)			2021			0.03 ( $\pm$ 0.03)	
	2022			0.06 ( $\pm$ 0.06)			2022			0.23 ( $\pm$ 0.08)	
	2023			0.17 ( $\pm$ 0.10)			2023			0.23 ( $\pm$ 0.10)	
<b>RVP</b>						<b>RVP</b>					
	2014	3.8 ( $\pm$ 0.3)	7.8 ( $\pm$ 0.9)	4.8 ( $\pm$ 0.4)	<b>5.6 (<math>\pm</math>0.2)</b>		2014	0.7 ( $\pm$ 0.11)	0.9 ( $\pm$ 0.25)	1.6 ( $\pm$ 0.50)	<b>1.0 (<math>\pm</math>0.20)</b>
	2015	4.5 ( $\pm$ 0.7)	3.1 ( $\pm$ 0.3)	3.6 ( $\pm$ 0.3)	<b>3.7 (<math>\pm</math>0.2)</b>		2015	0.4 ( $\pm$ 0.06)	0.4 ( $\pm$ 0.07)	0.2 ( $\pm$ 0.06)	<b>0.3 (<math>\pm</math>0.04)</b>
	2016	2.1 ( $\pm$ 1.1)	2.5 ( $\pm$ 0.8)	2.3 ( $\pm$ 0.8)	<b>2.3 (<math>\pm</math>0.6)</b>		2016	0.2 ( $\pm$ 0.10)	0.2 ( $\pm$ 0.10)	0.1 ( $\pm$ 0.07)	<b>0.2 (<math>\pm</math>0.05)</b>
	2017	2.0 ( $\pm$ 0.6)	2.3 ( $\pm$ 0.2)	1.5 ( $\pm$ 0.2)	<b>1.9 (<math>\pm</math>0.2)</b>		2017	0.2 ( $\pm$ 0.16)	0.2 ( $\pm$ 0.08)	0.1 ( $\pm$ 0.07)	<b>0.2 (<math>\pm</math>0.06)</b>
	2018	1.6 ( $\pm$ 0.2)	1.5 ( $\pm$ 0.3)	2.1 ( $\pm$ 0.2)	<b>1.7 (<math>\pm</math>0.2)</b>		2018	0.1 ( $\pm$ 0.07)	0.2 ( $\pm$ 0.10)	0.2 ( $\pm$ 0.07)	<b>0.2 (<math>\pm</math>0.05)</b>
	2019			0.9 ( $\pm$ 0.1)			2019			0.1 ( $\pm$ 0.06)	
	2020			0.6 ( $\pm$ 0.2)			2020			0.1 ( $\pm$ 0.1)	
	2021			0.2 ( $\pm$ 0.08)			2021			0.5 ( $\pm$ 0.13)	
	2022			0.73 ( $\pm$ 0.04)			2022			1.8 ( $\pm$ 0.3)	
	2023			0.47 ( $\pm$ 0.12)			2023			0.80 ( $\pm$ 0.13)	
<b>Pecan Island</b>						<b>Pecan Island</b>					
	2019			0.03 ( $\pm$ 0.03)			2019			0.0 ( $\pm$ 0.0)	
	2020			0.1 ( $\pm$ 0.1)			2020			0.0 ( $\pm$ 0.0)	
	2021			0.1 ( $\pm$ 0.07)			2021			0.03 ( $\pm$ 0.03)	
	2022			0.03 ( $\pm$ 0.03)			2022			0.0 ( $\pm$ 0.0)	
	2023			0.07 ( $\pm$ 0.07)			2023			0.03 ( $\pm$ 0.03)	
<b>OVERALL</b>						<b>OVERALL</b>					
	2014	2.9 ( $\pm$ 0.5)	4.9 ( $\pm$ 0.8)	6.7 ( $\pm$ 1.2)	<b>4.8 (<math>\pm</math>0.5)</b>		2014	0.3 ( $\pm$ 0.08)	0.4 ( $\pm$ 0.12)	0.9 ( $\pm$ 0.22)	<b>0.6 (<math>\pm</math>0.09)</b>
	2015	2.9 ( $\pm$ 0.3)	2.5 ( $\pm$ 0.2)	3.2 ( $\pm$ 0.2)	<b>2.9 (<math>\pm</math>0.1)</b>		2015	0.4 ( $\pm$ 0.04)	0.3 ( $\pm$ 0.04)	0.2 ( $\pm$ 0.03)	<b>0.3 (<math>\pm</math>0.02)</b>
	2016	1.6 ( $\pm$ 0.2)	2.0 ( $\pm$ 0.2)	1.9 ( $\pm$ 0.1)	<b>1.9 (<math>\pm</math>0.1)</b>		2016	0.1 ( $\pm$ 0.04)	0.2 ( $\pm$ 0.05)	0.1 ( $\pm$ 0.04)	<b>0.1 (<math>\pm</math>0.03)</b>
	2017	1.3 ( $\pm$ 0.2)	1.4 ( $\pm$ 0.2)	1.0 ( $\pm$ 0.1)	<b>1.2 (<math>\pm</math>0.1)</b>		2017	0.1 ( $\pm$ 0.06)	0.07 ( $\pm$ 0.03)	0.04 ( $\pm$ 0.03)	<b>0.07 (<math>\pm</math>0.02)</b>
	2018	1.0 ( $\pm$ 0.1)	1.1 ( $\pm$ 0.2)	1.3 ( $\pm$ 0.2)	<b>1.1 (<math>\pm</math>0.1)</b>		2018	0.07 ( $\pm$ 0.03)	0.1 ( $\pm$ 0.04)	0.1 ( $\pm$ 0.03)	<b>0.09 (<math>\pm</math>0.02)</b>
	2019			0.4 ( $\pm$ 0.1)			2019			0.1 ( $\pm$ 0.02)	
	2020			0.3 ( $\pm$ 0.1)			2020			0.1 ( $\pm$ 0.03)	
	2021			0.2 ( $\pm$ 0.05)			2021			0.2 ( $\pm$ 0.04)	
	2022			0.6 ( $\pm$ 0.37)			2022			0.75 ( $\pm$ 0.16)	
	2023			0.33 ( $\pm$ 0.08)			2023			0.41 ( $\pm$ 0.08)	



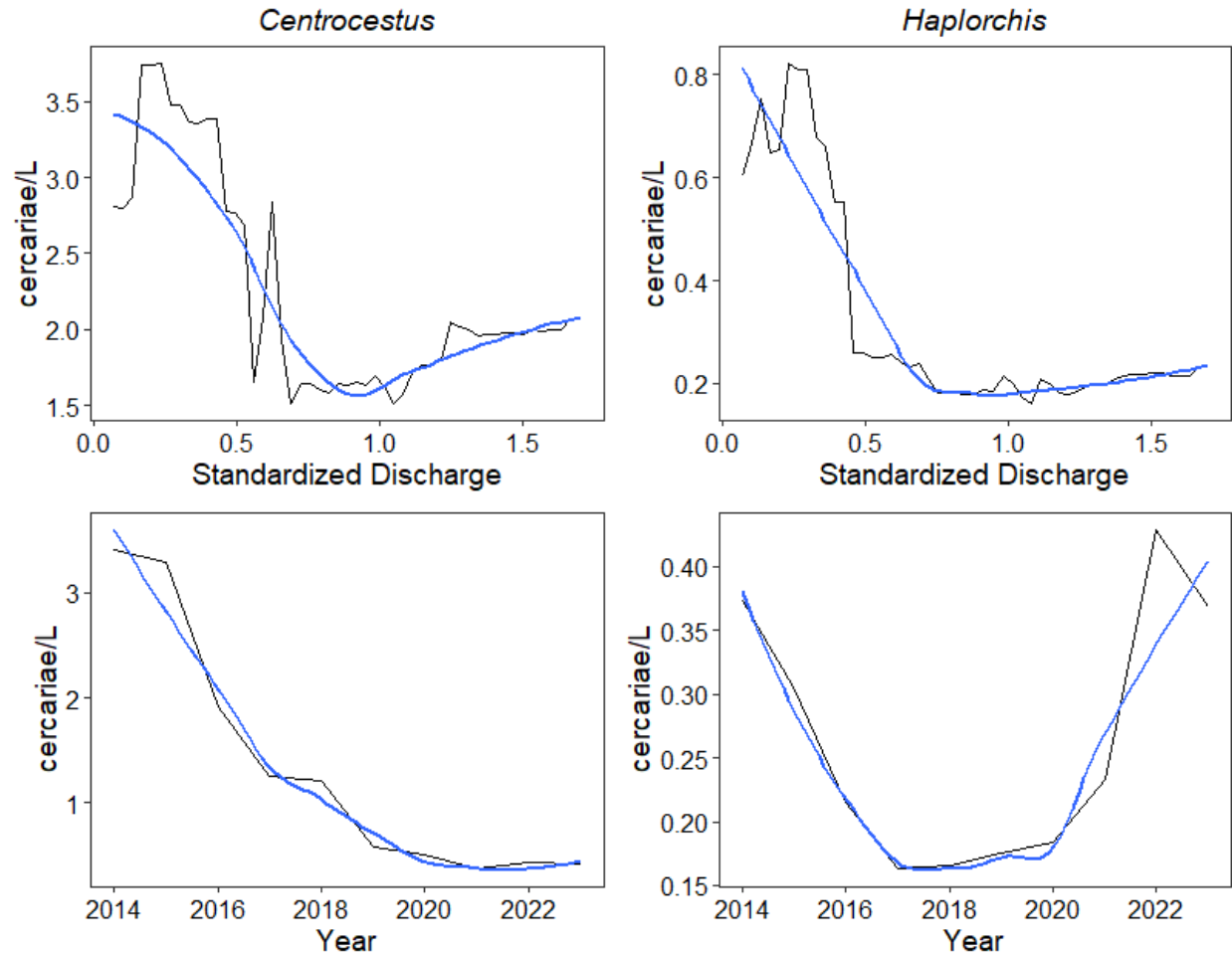
**Figure 2.** Times series displaying trends in standardized discharge during parasite monitoring at PI (top panel), LL (top panel), RVP (middle panel), and OCR (bottom panel). The blue line denotes LOESS smoothed regression fitted to observed standardized discharge values (black dots).

**Table 2.** Summary of optimal hyperparameters and predictive performance for random forest regression models used to examine trends in cercariae density in the Comal Springs/River System.

	<i>C. formosanus</i>	<i>H. pumilio</i>
<b>Model Hyperparameters</b>		
# of trees	500	500
# of variables tried per split	3	2
node size	5	5
<b>Model Performance Statistics</b>		
mean of squared residuals	0.75	0.08
% variation explained	84.19	48.73
correlation	0.92	0.70



**Figure 3.** Bar graph displaying the percent decrease in mean squared error (MSE) of variables used to predict *Centrocestus formosanus* and *Haplorchis pumilio* density in the Comal Springs/River system.



**Figure 4.** Partial dependence plots displaying the response of cercariae density as a function of standardized discharge and year for *Centrocestus formosanus* and *Haplorchis pumilio* in the Comal Springs/River system. The blue line denotes a loess smoothed regression of the fitted function. Note differences in y-axis scales for each panel.

## Discussion and Recommendations

Results from 2023 sampling provide further evidence to support that overall cercariae densities of *C. formosanus* have steadily declined since 2014. Mean density at each site decreased from 2014 to 2018 and continued to remain low up to 2023. Relative trends in *H. pumilio* cercariae density generally aligned with *C. formosanus* until 2020, where *H. pumilio* density began increasing to concentrations similar to 2014. While temporal trends differed relative to each species, their mean densities have been mostly congruent among sites since 2019.

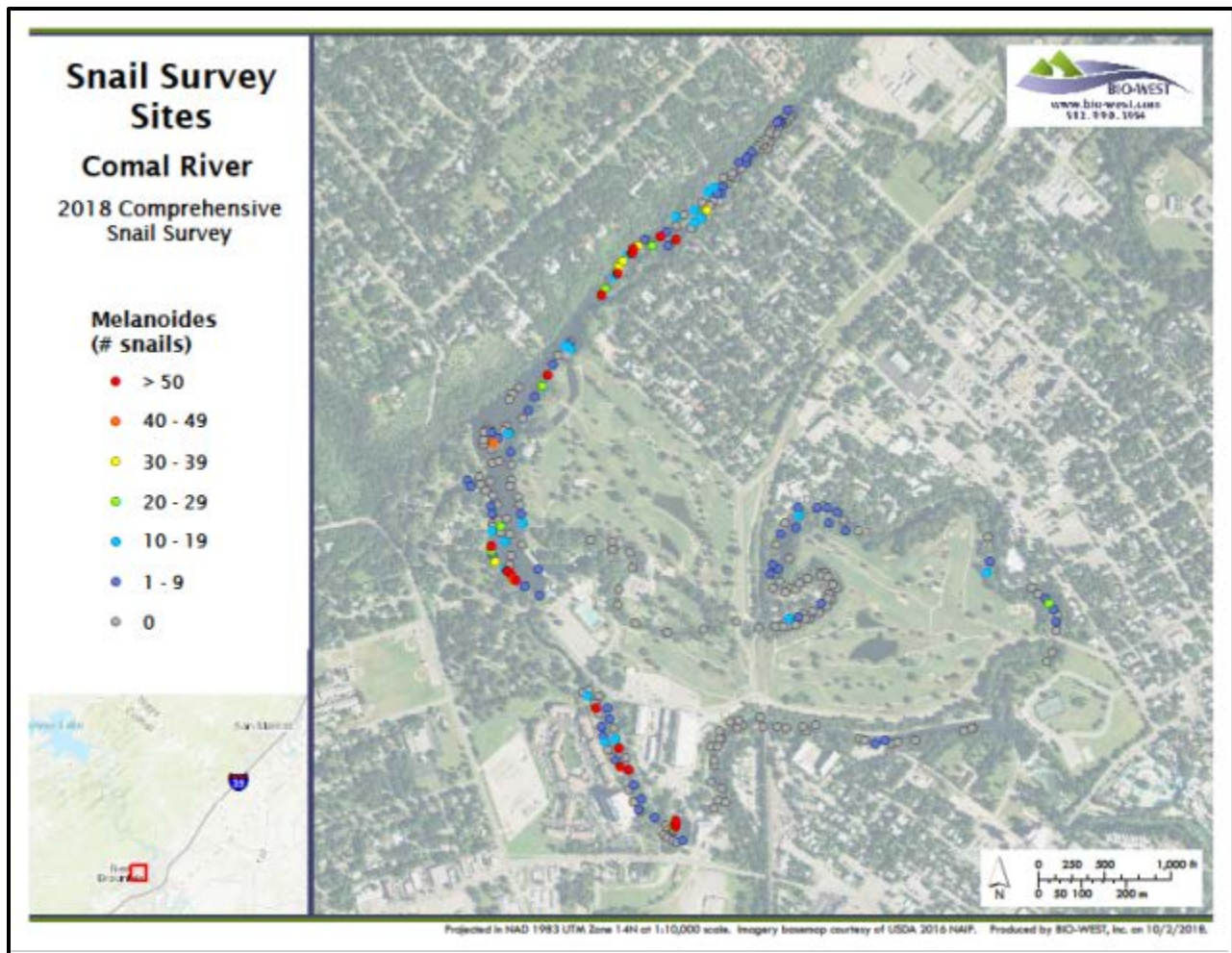
Random Forest models yielded similar predictive performance in 2023 and 2022, though the relative influence of covariates differed. The influence of year on predictions of *C. formosanus* density was much greater in 2023 compared to similar influences of standardized discharge and year in 2022. For *H. pumilio*, standardized discharge remained a highly influential predictor of



density, though site was more important in 2023 and had an effect size similar to standardized discharge; both were more influential than year. Despite differences in predictor importance, density relationships with standardized discharge and year displayed similar trends with past analyses. Cercariae density displayed a negative nonlinear relationship with standardized discharge, which confirms expectations regarding parasite-flow relationships. If cercariae production is assumed constant, densities naturally become diluted under high flow conditions and thus would be expected to increase at lower flows. That being said, the increased importance of year on predictive performance of *C. formosanus* density suggests other environmental and/or biotic mechanisms unaccounted for by the model have resulted in decreased densities of this species over time. Additionally, lower percent variation explained for *H. pumilio* indicates other important covariates not included in this analysis are likely missing for this species.

Recent declines in *C. formosanus* concentration could be related to recent trends in population dynamics of the host-snail *M. tuberculata*. In 2018, BIO-WEST collected data on snail distribution and densities throughout the study reaches, which showed large densities of *M. tuberculata* upstream of the LL and RVP transects (**Figure 5**). However, *M. tuberculata* data have not been collected since 2018. Collecting current data on snail distribution and density could help elucidate whether recent declines in *C. formosanus* concentration align with recent *M. tuberculata* population trends. There is also a lack of data on temporal changes in snail infection rates in the Comal system. Although a study from the late 1990s found ~6% of *M. tuberculata* were shedding *C. formosanus* (Mitchell et al. 2000), it is unknown if that percentage has changed through time. Lastly, there is a lack of data on definitive host (i.e., bird) infection rates and data on the number and intensity of infected fish in the system are exclusively based on manipulated experiments (McDonald et al. 2006; Huston et al. 2014; Scott 2019). Data collection on infection rates in all three of the parasites hosts under more natural conditions would allow a more complete understanding of parasite population dynamics.

In summary, parasite monitoring show that the two sites (RVP, PI) with the highest densities of *C. formosanus* and *H. pumilio* in 2022 generally had lower densities in 2023, but already low densities of both parasites at the other sites were unchanged. Trends since 2014 display that *C. formosanus* has decreased substantially, whereas *H. pumilio* has shown recent increases in density to levels similar to 2014. That being said, overall densities were less than 1 cercariae/L for both species. Results from this analysis show that Random Forest regression models can be used to better inform the EAHCP process specific to *C. formosanus*. Incorporating additional data, as described above, could provide a more mechanistic understanding on ecological factors driving parasite population dynamics for both species, including recent declines in *C. formosanus*, despite lower system-level discharge since 2021, and could also help improve predictions of *H. pumilio* density. At a minimum, continued monitoring of parasite concentrations in the Comal Springs/River system is important to provide data at flow levels not yet observed, as well as to assess responses of the *C. formosanus* population when flows return to normal magnitudes.



**Figure 5.** 2018 comprehensive survey of *M. tuberculata* in the Comal River.

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## Appendix H5 | **Riffle Beetle Riparian Habitat Restoration**





## MEMORANDUM

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To: Phillip Quast

From: Casey Williams

Date: December 21, 2023

Subject: Progress on the Riffle Beetle Restoration Project for 2023

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Phillip,

Below is an update on activities we carried out for the Comal riffle beetle / riparian habitat restoration along Spring Run 2, Spring Run 3 and Western shoreline in Landa Park. The newest addition to the project, Spring Run 2 has filled in nicely despite the dry conditions we have had. Here is a rundown of the work we have done over the course of the year.

- January / February- We planted several one-gallon native trees along the Spring run 3 and Western shoreline. These included live oak, hackberry, cedar elm and red oak. We added more cages around plants to protect from herbivory.
- March-May- We trimmed all old vegetative growth along Spring run 3 to the ground to allow for new spring growth. We planted buttonbush and elderberry cuttings along both sides of Spring Run 3 and some along Western shoreline. Reseeded Spring run 2 with Sideoats gramma. Added more native grasses including *Leersia monandra* and Melic grass. Maintained cages around surviving shrubs and trees.
- June – November- We continued to maintain the area with occasional trimming, checking on fencing and enclosures and readjusting/mending as necessary. We hand watered Spring run 2 with the water hose to get it through the drought. With it being so hot and dry we held off on plantings and some other activities. We planted (3) 1 gallon sycamore trees along Spring run 3 and Western shoreline. Added native seed to Spring run 2 slope including Red salvia, Inland sea oats, Blue curls and Ohio spiderwort.
- December – We added 12 coconut coir erosion control logs to the slope along Spring run 2 and to upper hillside of Spring run 3 to slow runoff water, catch sediment and build soil. We maintained the water diversion barrier along the Spring run 3 hillside. We also selectively removed branches and shrubs to open up more canopy for sunlight and left brush piles along the slope of Spring run 2 to discourage herbivory and human traffic. We planted several more native perennials, trees and shrubs including Madrone, Red buckeye, Ironweed, various sedges and grasses. These plants were donated by San

Antonio Botanical Gardens and Medina Nursery. We seeded Turks cap, Frost weed, Inland sea oats to both spring runs.

We continue to notice more vegetation establishment along Spring run 2 and 3 hillsides. Even during the drought new vegetation has emerged. Some problematic points include continued undercutting along some stream edges and the rock wall along Spring run 3. This can pose a future stream side erosion risk as these areas become more unstable. We would propose shoring up these areas in some way. Specific to Spring run 3, there continues to be social trails cut across the vegetation buffer to access the water. We have tried various methods at discouraging these including brush piles (which were subsequently removed by another party), fenced cages and more plantings. It is likely it will take some continued effort to discourage foot traffic and repair damage.

We are happy to be involved in this project and the progress made in the last few years has been exciting to watch.

Sincerely,  
Casey Williams



**Figure 1. Spring run 2 slope and beds in the winter of 2023.**





**Figure 2. Low water levels have undermined several portions of the rock wall along Spring run 3. Some areas of the wall have completely caved in undermining vegetation roots. Areas like this are susceptible to collapse and further erosion.**





**Figure 3. Vegetation buffer along Spring run 2 during one of the lowest discharge rates for Comal Springs (top). Area along Spring run 2 during growing season (bottom).**

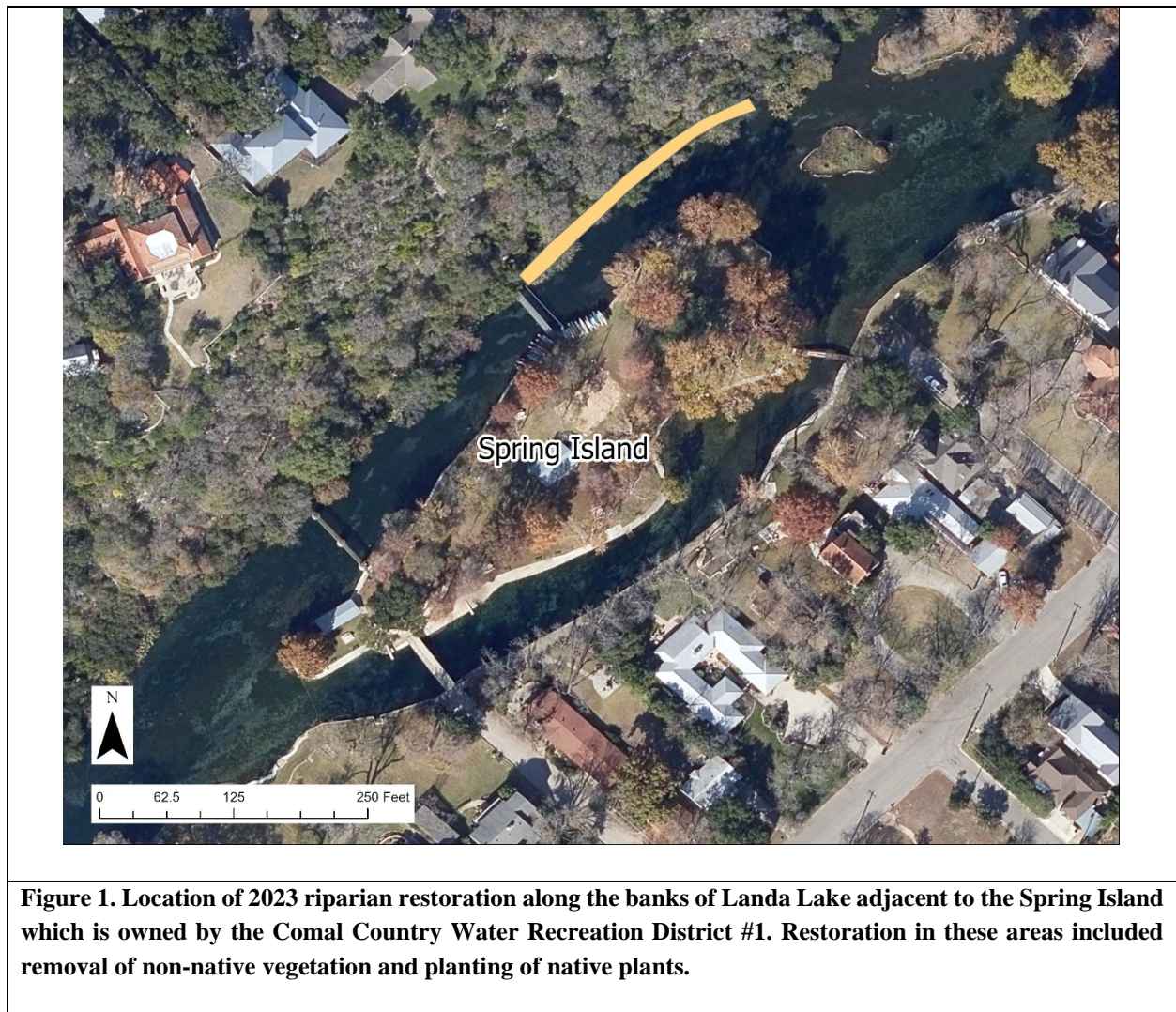


## Appendix H6 | **Native Riparian Habitat Restoration**



### CoNB Native Riparian Habitat Restoration (EAHCP § 5.7.1)

The primary riparian restoration activities conducted in 2023 include: 1) removal and control of non-native riparian vegetation along Landa Lake on Comal County Water Recreation District property near Spring Island, near Pavilion 16 in Landa Park, and along the New Channel/ Mill Race in Landa Park, 2) planting of native vegetation in areas where non-native vegetation was previously treated/ removed, 3) establishment of erosion/ sediment control berms and, 4) maintenance of previously restored areas within the riparian zone of Landa Lake and the Old Channel for the Comal River. **Figure 1, Figure 2, and Figure 3** illustrate the areas where riparian restoration activities occurred for the first time in 2023.



**Figure 1. Location of 2023 riparian restoration along the banks of Landa Lake adjacent to the Spring Island which is owned by the Comal County Water Recreation District #1. Restoration in these areas included removal of non-native vegetation and planting of native plants.**





**Figure 2. Location of 2023 riparian restoration along New Channel/ Mill Race of the Comal River. Restoration in this area to include removal of non-native vegetation, installation of erosion/ sediment control berms, and planting of native plants.**





The non-native vegetation species targeted in 2023 include, but were not limited to, elephant ear (*Colocasia* sp.), privet (*Ligustrum* sp.), Chinese tallow (*Triadica sebifera*), giant cane (*Arundo donax*), and chinaberry (*Melia azedarach*). Approximately 110 *Ligustrum* (including 9 large trees and 101 small trees/ saplings), 1,006 Chinese tallow (including 26 large trees and 980 small trees/ saplings) and 683 Chinaberry (including 7 large trees and 676 small trees/ saplings) were removed/ treated throughout the riparian zone in 2023, primarily along the shores of Landa Lake and the bank of the new channel of the Comal River.

Maintenance activities, including the re-treatment of re-emergent non-native vegetation and supplemental planting, occurred within previously restored areas extending from the upstream portion of Landa Lake through the Old Channel of the Comal River to the end of the Old Channel LTBG reach.

In 2023, approximately 597 native plants were planted and 5lbs. of native grass seed distributed within the riparian zone along Landa Lake primarily within the areas delineated in **Figure 1, Figure 2, and Figure 3**. The species and the total number of plants introduced into riparian areas in 2023 is shown in **Table 1**.

<b>Table 1. Native Plants Planted within Riparian Zones Throughout the Comal River System in 2023</b>	
<b>Native Plants</b>	
Agarita	3
Big Muhly	15
Butterfly Milkweed	40
Cedar Sage	20
Deer Muhly	5
Eastern Gamagrass	7
Emory Sedge	170
Inland Sea Oats	63
Lindheimer Muhly	51
Little Bluestem	43
Nimblewill	40
Rockrose	6
Skeleton Leaf	20
Straggler Daisy	40
Texas Lantana	6
Texas Mountain Laurel	13
Texas Persimmon	2
Texas Sage/ Cenizo	6
Turk's Cap	10
Virginia Creeper	15
Woodland Creek Sedge	40
Yellow Bells	3
Yucca, Red	2
Yucca, Twist Leaf	2
Zexmenia	15
<b>Native Plant Seed Distributed</b>	
Native Turf Blend – Blue Grama and Buffalograss	5 lbs.
<b>Total # of native plantings: 597 (plus approx. 5 lbs. seed distributed)</b>	



**Photo Log**



**Photo 1** Example photo of a treated stump of a Ligustrum near Spring Island (Figure 1).



**Photo 2.** Photo of a newly-planted Emory Sedge along Mill Race in Landa Park (Figure 2).





**Photo 3.** Photo of contractors removing various nonnative plant species near Spring Island (Figure 1).



**Photo 4.** Photo of contractor planting a Texas Mountain Laurel along Mill Race in Landa Park (Figure 2).



## Appendix H7 | **Impervious Cover and Water Quality Protection**



## **City of New Braunfels**

### **Impervious Cover and Water Quality Protection (EAHCP § 5.7.6) – 2023**

Excerpt from Landa Park Aquatic Center Water Quality Retrofit Technical Memorandum:

“The existing Aquatic Center parking lot is proposed to be retrofitted with a bioretention basin to treat stormwater runoff from the entire parking lot. Currently, the approximate 2-acre parking lot drains directly to the Comal River. The proposed bioretention basin will use a concrete wall (height = 2 feet) with a form liner to have the appearance of a stacked rock wall. In addition, native plants and trees will be planted in the basin to enhance appearance, improve water quality management, and provide parking lot shade. Wheel stops are proposed along with a ribbon curb so that parking lot runoff will sheet flow into the basin, thus, avoiding concentrated discharge points and the potential for sediment accumulation that can impeded flow. Existing trees will be preserved and the bioretention outlet will use a 24” reinforced concrete pipe to connect to an existing stormwater inlet and pipe that currently discharges to the Comal River.

The bioretention basin water quality component was designed per the TCEQ Edwards Aquifer Protection Program, RG-348 Manual. Bioretention soil media per the TCEQ guidance is proposed to promote infiltration and support long-term pollution management. Upgradient of the biofiltration component, a bioswale is proposed at a slope of 0.6% to promote filtering and nutrient uptake.

#### **Key project statistics:**

**Drainage area = 1.91 acres**

**Impervious area = 1.59 acres (83%)**

**Water quality volume provided = 3,241 cubic feet at elevation 624.5.**

**Biofiltration media elevation = 623.1**

**Total suspended sediment managed per year = 1,427 pounds”**

Technical Memorandum prepared for the City of New Braunfels by Tom Hegemier, P.E., D.WRE, CFM and Oscar Flores, EIT, December 29, 2020

Landa Park Aquatic Center parking lot rehabilitation and biofiltration system was completed in April 2023. The following are example photos of the completed project:

