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Flow Enhancement Feasibility Study for Part of Redwood Creek in the South Fork Eel River Watershed.

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Cover photo: Photo taken 30 September 2016 highlighting extreme low flows in the Feasibility Study area. Photo depicts completely dry stream reach of Miller Creek located approximately 1.5 miles upstream from the Redwood Creek confluence.

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1 INTRODUCTION

The Salmonid Restoration Federation (SRF), working under California Department of Fish and Wildlife (CDFW) Grant #: D1410509, contracted Stillwater Sciences to evaluate flow enhancement opportunities within a portion of Redwood Creek (tributary to the South Fork Eel River near Redway). The goal of the project is to determine the general feasibility of water management activities, as well as the most effective short- and long-term actions that will enhance dry season flows. The study area addressed in this report includes the Miller Creek sub-basin and a portion of mainstem Redwood Creek as shown on Figure 1. The project team is seeking funding to expand flow enhancement efforts in Redwood Creek beyond the limits of this study area.

This feasibility study is based in part on existing flow monitoring data and the target flow analyses presented in the Redwood Creek *Target Flow Technical Memorandum* (Appendix A, previously prepared under this contract). In the *Target Flow Memo*, a range of flows within the study area are identified that provide varying degrees of habitat value (Appendix A, Figure 3). These potential ecological flow targets may be refined following completion of a flow study currently being conducted by CDFW in Redwood Creek, however, flow targets recommended by CDFW will likely fall within the lower and upper target flows bracketed in Appendix A, Figure 3. Stillwater Sciences concludes from these targets, hydrologic modeling, and additional analyses that even if human consumptive use was completely curtailed (i.e. complete storage and forbearance across the entire study area), dry season flows are unlikely to be higher than the target that provides the minimum flow for fish connectivity except during the wettest water years.

Considering that implementing storage and forbearance throughout the study area could take decades to complete and that ideal flow targets will likely be above the minimum flow for fish connectivity, a combination of multiple flow enhancement methods have been analyzed including: (1) storage and forbearance (addressing impacts of human consumptive use only); (2) groundwater recharge; and (3) direct flow enhancement (via input from ponds). The extreme low flows (zero flow in many cases) measured during the past three dry seasons within the study area suggest a combination of flow enhancement approaches will be necessary.

The feasibility study focuses on seven components: (1) existing consumptive water use within the study area, (2) types of flow enhancement activities that are most applicable to the study area and are likely to generate meaningful results, (3) suitability of new and existing locations for water storage, (4) willingness of landowner participation in a storage and forbearance program, (5) water rights and regulatory framework, (6) potential positive and negative impacts of water storage on instream flow, and (7) costs and benefits of different flow enhancement techniques.

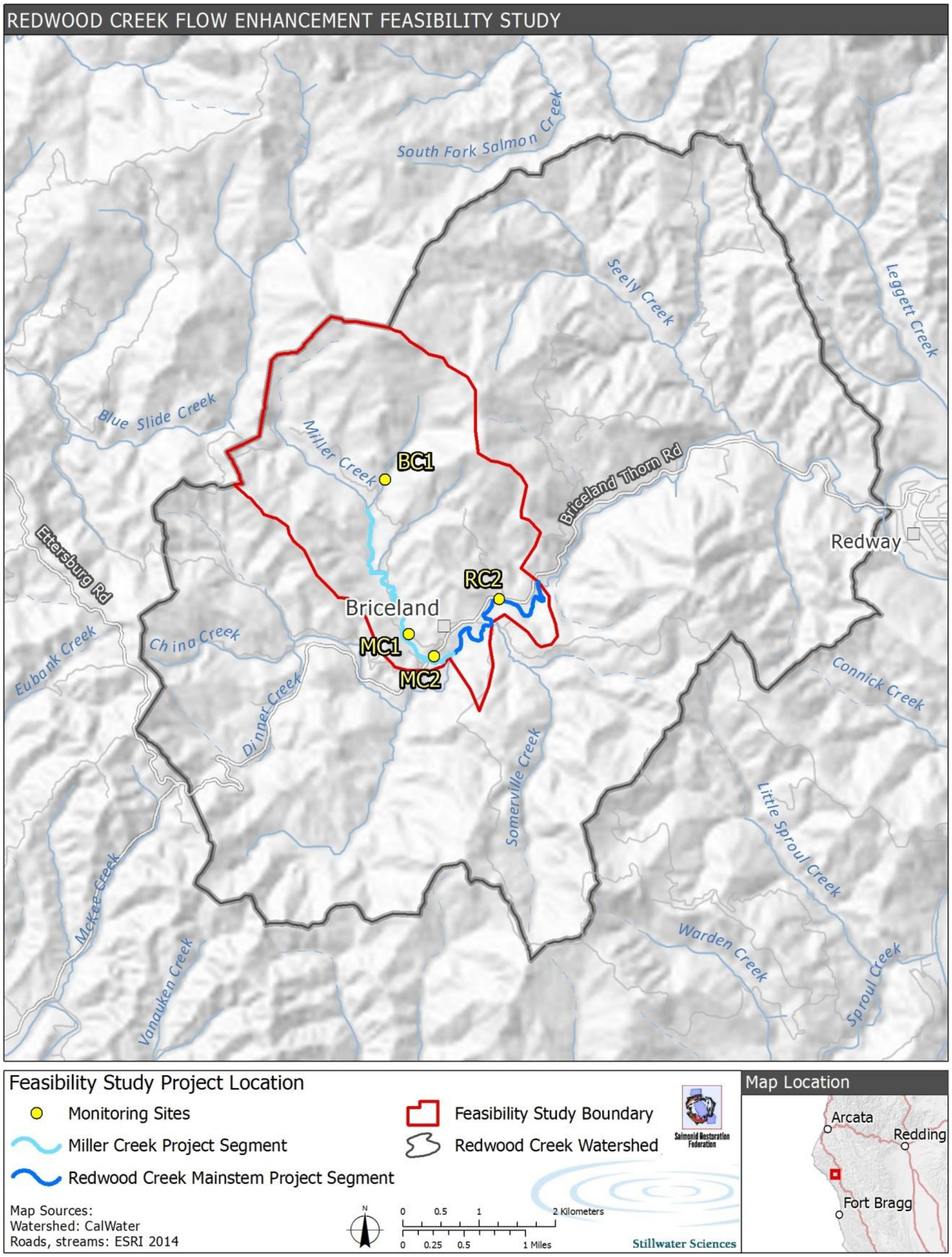


Figure 1. Redwood Creek feasibility study area.

2 EXISTING CONSUMPTIVE HUMAN WATER USE

Determining the volume of existing consumptive water use within the study area shown on Figure 1 is a critical component of this feasibility study. However, as is the case with many rural areas with dispersed water sources and users, quantification of consumptive use is difficult. Considering this difficulty, Stillwater Sciences used several different approaches to quantify water use, including: (1) landowner responses to a water use survey conducted within the study area by SRF, (2) landowner responses from a survey conducted by Sanctuary Forest in the adjacent Mattole River watershed, (3) information reported in Bauer et al. 2015[1], and (4) new GIS analyses conducted within the study area that estimated water use based on area of agricultural cultivation determined from aerial imagery. Each approach for estimating water use is described below and summarized on Table 1.

2.1 Landowner Responses within the Study Area

A water use survey was sent to 100 residents within the study area. Response rate was 12%. Based on the 12 responses, average domestic (i.e. household) water use was 102 gallons per day and average irrigation use was 376 gallons per day for a total average water use of 478 gallons per day (Table 1). The low response rate and relatively low resulting estimate of average daily use suggests that many of the larger water users within the study area did not respond, and therefore it may not be appropriate to apply these results more broadly across the entire watershed area. Despite the limited sample size, the survey provided some interesting findings:

- Approximately half of respondents use a spring as their water source for domestic and irrigation water supply.
- Only 1/3 of the respondents have separate domestic and irrigation water systems.
- Half of respondents are currently forbearing for 3 or 4 months.
- Water storage capacity varied widely among respondents.

Appendix B includes more complete survey results.

[1] Bauer, S., J. Olson, A. Cockrill, M. Van Hattem, L. Miller, M. Tauzer, and G. Leppig. 2015. Impacts of surface water diversions for marijuana cultivation on aquatic habitat in four northwestern California watersheds. PLoS ONE 10: e0120016. doi:10.1371/journal.
pone.0120016.

Table 1. Consumptive water use estimates.

Water Use estimate approach	Estimated water use per parcel (gal/day)	Total water use per parcel during 5-month growing season (gal)	Total project area water use (gallons/ minute)	Total project area water use (cubic ft/sec)
1) Redwood Creek water use survey	478	71,700	26	0.058
2) Upper Mattole water use survey	708	106,200	38	0.085
3) CDFW data for Study Area (from Bauer et. al. 2015)	725	108,750	39	0.087
4) Updated GIS analyses of study area	925	138,750	49	0.11

2.2 Landowner Responses from Adjacent Watersheds

A water survey of 40 residents in the upper Mattole River resulted in an average estimated water use of 708 gallons per day during the 6-month dry season (Table 1) (Trout Unlimited 2013[2]). Results from this survey are applicable to the Redwood Creek study area considering that the upper Mattole River is located directly adjacent to, and west of the Redwood Creek study area and the Mattole watershed has many of the same physiographic, ecological, and land use characteristics.

2.3 Compilation of CDFW Data for the Redwood Creek Study Area

Using the mapping and assumptions of Bauer et al. (2015), Stillwater Sciences estimated cannabis-related water use within the Redwood Creek feasibility study area. The approach involved GIS overlay of the study area boundary and the Bauer et al. (2015) mapping. Estimates of cannabis irrigation on 77 parcels in the study area averaged 425 gallons per day (excludes parcels serviced with water from the Briceland Community Service District). This included approximately 36,000 ft^2 of greenhouse and 2,200 outdoor cannabis plants. When average domestic use of approximately 300 gallons per day per parcel was added, the average water use determined through this method is 725 gallons per day (Table 1). The results of this analysis were generally consistent with results from the upper Mattole River survey.

2.4 Updated GIS Analyses

Since estimates of water use for cannabis cultivation by Bauer et al. (2015) was based on 2012 aerial imagery, the desktop GIS analyses of water use within the study area was updated based on

[2] Trout Unlimited. 2013. Mattole River Headwaters Streamflow Improvement Plan.

2014 aerial imagery. This analyses considered consumptive water use for cannabis cultivation, as well as other land uses (e.g., vegetable gardens and landscaping). Primary results of the analyses include:

- Greenhouse square footage 53,000 (increase of 17,000 square feet from 2012 to 2014)
- Outdoor cannabis plants 2,800 (increase of 600 from 2012 to 2014).
- ~5.6 acres of vegetable gardens, orchards, and vineyards that weren't included in CDFW analyses.

Estimated water use (gallons per day) was then updated using these data and the following assumptions:

- Input from cultivators suggests cannabis plants in greenhouses typically require 3 gallons per day (lower than that estimated by Bauer et al. [2015]).
- Cultivation of outdoor cannabis plants typically requires 6 gallons per day per, a relatively high estimate that accounts for inefficiencies evident in many irrigation systems.
- For other irrigated areas the following formula was used:

(Eto x PF x SF x 0.62) / IE =Gallons of Water per day[3]

Where:

Eto = evapotranspiration factor. Taken from http://www.rainmaster.com/historicET.aspx and using zip code 95553 a value of 0.16 is obtained.

PF = plant factor. Typically, a value of 1.0 is used for lawn 0.80 for water loving shrubs, 0.5 for average water use shrubs, and 0.3 for low water use shrubs (0.5 was used).

SF = irrigated area (square feet).

0.62 = constant.

IE = irrigation efficiency factor. This value compensates for irrigation water that isn't used by the plant. Efficient sprinkler systems with little run-off can have efficiencies of 80%. Drip irrigation systems typically have efficiencies of 90%. (A value of 0.75 was used to account for general leakage and inefficiencies seen in most rural water systems).

Based on these assumptions and calculations, the average water use per parcel was 625 gallons per day for irrigation. Irrigation for cannabis cultivation accounts for 66% and non-cannabis irrigation accounts for 34% of total estimated irrigation use. When domestic use of 300 gallons per day is included, the total estimated water use per parcel increases to 925 gallons per day (Table 1). Over the five-month dry season, this equals 93,750 gallons of irrigation water and 45,000 gallons of domestic water.

Based on these analyses, 1,000 gallons per day per parcel is a reasonable and conservative estimate for total water use within the feasibility study area (as used in the target flow memorandum).

[3] http://www.irrigationtutorials.com/how-to-estimate-water-useage-required-for-an-irrigation-system/

3 APPLICABLE FLOW ENHANCEMENT ACTIVITIES

Three primary types of flow enhancement activities are being used in north coastal California:

1. Storage and forbearance is a flow enhancement approach that aims to reduce the impact of human consumptive use by storing water during the wet season and using that water during the dry season to avoid any additional withdrawals. This approach has been implemented successfully in the upper Mattole watershed focusing on installation of tank storage. Ponds may also provide cost-effective water storage for dry-season agricultural use.
2. Groundwater recharge is a flow enhancement approach that stores water during the wet season in ponds, with shallow groundwater slowly discharging from the ponded area to downslope springs and stream channels during the summer months. While promising, this approach requires more planning, design, and implementation work to demonstrate proof of concept. Several new pilot projects apply this approach at a variety of spatial scales in the Mattole watershed.
3. Direct flow enhancement is a more intensively managed flow enhancement approach that delivers surface water stored in ponds (or other sources) directly to a stream reach via a plumbed system. This approach has been recently implemented by the SWRCB in critical stream reaches in Sonoma County.

Stillwater Sciences believes that the most effective approach for flow enhancement will utilize a combination of the three types of flow enhancement activities described above. Watershed and site-specific opportunities and constraints will determine the most effective and appropriate combination.

4 SUITABILITY OF WATER STORAGE LOCATIONS

Based on preliminary geologic and topographic analyses and site visits to more than 50 properties within the Redwood Creek feasibility study area and vicinity, the technical team believe that at least 80% of the parcels have suitable locations for a combination of small lined ponds and/or pads for tanks that will have sufficient storage capacity to supply domestic and irrigation needs for that specific parcel during a 3 to 5 month forbearance period. Fewer potential opportunities exist for unlined groundwater recharge ponds or other large storage systems for direct flow enhancement. Typically, these types of structures need lower gradient topography and soils that contain a clay content of >20%, which typically occur in grasslands or prairies. There are some large unlined ponds to the northwest of the town of Briceland that are likely providing groundwater recharge benefit. During the final two months of this project, field work was conducted to assess potential groundwater recharge sites and locations for other large scale storage systems. Several sites with high potential were identified and are further described in Section 10 below.

In the next phase of this project (pending grant funding), Stillwater Sciences will develop a GIS tool that identifies potentially suitable large-scale groundwater recharge and/or surface storage sites based on topography, soils, vegetation cover, land use, and proximity to watercourses.

5 LANDOWNER PARTICIPATION

Overall, landowners have expressed strong interest in the project, and many landowners are voluntarily increasing their water storage through construction of ponds and installation of tanks. Outreach is ongoing, and it is likely that a majority of landowners would participate in water conservation and streamflow enhancement initiatives if financial support and other incentives were available. The project team recognizes, however, that landowners will need to bear the majority of the cost for water storage, especially if it is used for commercial agricultural purposes. As with any community, some landowners may choose not to participate. However, recent CDFW enforcement actions, if followed up by appropriate outreach and technical support, may motivate many people to comply with water diversion and storage requirements. It will be important for landowners to have ongoing technical and organizational support to guide the timing of forbearance periods based on stream flow characteristics, following the Mattole model.

6 WATER RIGHTS

Water rights and California Water Laws remain a challenge for project implementation because there is currently no cost-effective mechanism to permit projects that capture winter runoff from streams, store it for longer than 30 days, and use that stored water for commercial agriculture. Storing large volumes of winter runoff for direct flow enhancement during the dry season would likely require an appropriative water right. Using rainwater catchment ponds for irrigation water supply, however, is an approach that does not require significant permitting. Permits for small domestic water storage can allow people to collect water during the winter and store it through the summer as long as it is not used for commercial agriculture. The combination of these approaches may offer a feasible, cost-effective strategy for most landowners. Additionally, the SWRCB is working on a Small Irrigation Use permitting pathway that will allow for storage of surface water from springs or creeks under certain conditions. The SWRCB anticipates that this permitting option will be available by the summer of 2017.

7 POTENTIAL IMPACTS OF FLOW ENHANCEMENT ACTIVITIES

Based on observations within the project area and elsewhere throughout the region, flow enhancement activities can result in four general categories of potential negative impacts: increased erosion, reduction in flows during active diversions, lower water quality, and introduction of invasive species. In all cases, these potential impacts can be avoided and/or mitigated through appropriate planning, design, and maintenance.

7.1 Erosion Potential

Ponds (or tank flats) that are not constructed at suitable locations or engineered properly have the potential to cause significant negative impacts, including increased surface erosion and/or mass wasting. In the worse-case scenario, failed ponds and/or fill slopes can cause significant gullying or landslides. Experienced licensed professionals should design all ponds and grading sites, and experienced licensed contractors should perform all construction work. Long-term monitoring and maintenance by the landowner is also critical to insure that all project components are functioning as designed.

7.2 Reduction in Fall and Spring Streamflows

If water is stored in ponds or tanks during the wet season, it has the potential to reduce stream flows during this period. Typically, the most critical periods to minimize diversions (in addition to the dry season) are during (1) the late fall and early winter when streamflows first rise and fish begin to move into and within the system, and (2) the spring and early summer when flows recede and fish require suitable flow and temperature to avoid stressful low-flow conditions. Most small-scale storage projects (e.g., rainwater catchment ponds) located away from stream channels can be managed to avoid risks to in-channel aquatic resources during these periods. However, landowner need to carefully manage their storage and conveyance systems. It can be detrimental to instream conditions if ponds or tanks are "topped-off" late in the spring. As these types of projects become more widespread, the cumulative impacts must be closely examined. Ideally, projects should be designed to capture water during the wettest portions of the winter to avoid adverse effects to the fall and/or spring flows.

7.3 Water Quality

Water quality may be a concern where water stored in a pond is delivered directly to a stream for flow enhancement. The primary water quality issues are high temperature and/or low dissolved oxygen. These concerns can be mitigated by running flow through subsurface soil and gravel. Experimental projects of this type were conducted by the California State Water Quality Control Board (SWRCB) in Sonoma County in the summer of 2015. Agricultural pond water was used for direct flow enhancement in critical fish-bearing streams that were going dry. Initially, the quality of the stored water was not suitable for flow enhancement. However, when it was allowed to flow through substrate and mix with ground water, the resulting input to streamflow was suitable for aquatic habitat and the methodology proved effective for increasing stream flow.[4] Addressing these types of water quality concerns must be a key factor that guides the design of any direct flow enhancement project.

7.4 Invasive Species

The potential to introduce and propagate invasive species (e.g., bullfrogs, canary reed grass, mosquitos, bass and other Centrarchids) can be an important issue in building ponds. Ponds design plans (especially those in close proximity to a creek) should include a plan to manage and/or eradicate invasive species. At a minimum, periodically draining the pond every year or another type of bullfrog eradication plan is necessary.

8 COST ASSESSMENTS

Stillwater Sciences assessed the cost of different water storage techniques considering all of the necessary steps for a fully operational system. Costs typically fall within the following categories: (1) site assessment, engineering, and permitting; (2) earthwork; (3) water storage (pond liners/tanks); and (4) plumbing system upgrade. Tables 2 describes typical costs for 100,000 gal and 300,000 gal water storage systems. Note that the estimate costs described below are typical averages and should not be used for specific project design.

[4] Schultz, Daniel, CA State Water Resources Control Board presentation at 2016 Salmonid Restoration Federation Annual Conference.

Table 2. Typical costs for common water storage projects.

	Site assessment, Engineering, and permitting	Earthwork	Water storage supplies—pond liners/tanks	Plumbing	Total	Cost per gallon
100,000 gallon system						
Water tank system	$10,000	$5,000	$80,000	$5,000	$100,000	$1.00
Lined pond	$10,000	$10,000	$5,000	$2,500	$27,500	$0.28
Unlined pond	$10,000	$10,000		$2,500	$22,500	$0.23
300,000 gallon system						
Water tank system	$10,000	$5,000	$240,000	$15,000	$270,000	$0.90
Lined pond	$10,000	$20,000	$10,000	$2,500	$42,500	$0.14
Unlined pond	$10,000	$20,000		$2,500	$32,500	$0.11
Average						
Water tank system						$0.95
Lined pond						$0.22
Unlined pond						$0.17

Table 2 highlights the fact that water tank systems are significantly more expensive than ponds at a per-gallon rate. Additionally, larger ponds become more cost effective whereas tank systems have little economy of scale. Based on these considerations, landowners can achieve significantly more water storage for the same investment utilizing ponds instead of tanks for their agricultural storage. Based on the water use estimates previously described in Table 1, if all landowners in the watershed fully forbear from diversion for the five-month dry season, each parcel on average would need 45,000 gallons of storage for domestic use and approximately 100,000 gallons of storage for irrigation use. Based on these water storage volumes, the total cost of water storage for the study area has been calculated and summarized in Table 3. These calculations include the following assumptions: unlined ponds cost $0.23/gallon; lined ponds cost $0.28/gallon; tanks cost $1.00/gallon (values for 100,000 gallon system from Table 2). Note that significant additional cost savings could be achieved by landowners pooling resources to construct larger ponds where feasible (i.e. community water systems).

Table 3. Cost assessment for project area water storage for human consumptive use.

Approach per parcel	# parcels	Volume tanks (gal)	Volume lined ponds (gal)	Volume recharge ponds (gal)	Total cost
1) All tanks	77	11,165,000	-	-	$11,165,000
2) Tanks for domestic; lined ponds for ag irrigation	77	3,465,000	7,700,000	-	$5,621,000
3) 10,000 gallons of tank storage for domestic use; 35,000 gallons of groundwater recharge ponds to offset domestic use; lined ponds for ag irrigation	77	770,000	7,700,000	2,695,000	$3,545,850

Table 3 highlights the large variation in costs associated with different water storage and flow enhancement approaches. An approach utilizing a combination of tanks, lined ponds, and groundwater recharge is estimated to produce the same flow benefits as utilizing exclusively tanks but at 30% of the cost. Additional savings may be realized by developing "community water systems". More research and development on the effects of groundwater recharge projects on flow enhancement is needed to effectively incorporate that approach into a long-term strategy.

Assuming an average cost of $0.17 per gallon for unlined ponds (Table 2) and a sufficient number of appropriate sites, it would cost approximately $2,000,000 to construct 12,000,000 gallons of storage for groundwater recharge and/or direct flow enhancement (the amount of water required to meet the needs and/or offset the use of all landowners in the project area for five months). Note that as shown on Table 2, this cost includes design, permitting and construction. Funding a project of this size and cost is appropriate and feasible through existing state and federal grant programs, especially considering the cumulative effort these programs have expended to date on fisheries restoration projects that depend on sufficient streamflow to succeed and the future risks to listed fish within the watershed. However, a 12,000,000 gallon project will only approximately offset human consumptive use, so a long term plan for the watershed should include additional storage volume allocated specifically to meet flow enhancement objectives beyond accounting for human consumptive use alone.

9 CONCEPTUAL DESIGNS AND TEN-YEAR PLAN

As the final phase of this project, a 10-year plan was developed that identifies and prioritizes site-specific implementation actions to increase dry season flow. It is important to note that this project included targeted field assessments rather than a complete watershed assessment. The plan presented here outlines a framework with key steps to meet flow enhancement objectives and should be considered a work in progress that will be updated as additional funding becomes available for outreach and more detailed assessment. The recommendations included within this plan should be revisited based on the measured results from flow enhancement projects underway throughout the region.

9.1 Existing Stream Channel Conditions

A key step in developing recommendations for flow enhancement activities is understanding the stream channels within the study area in terms of flow dynamics and habitat for anadromous fish. Again, this project did not include detailed inventory of aquatic habitat conditions or fish distribution and abundance, nor did it include a formal instream flow assessment that identifies the magnitude and timing of flows required to meet specific ecological objectives. However, the framework and recommendations are strongly supported by flow monitoring results, targeted field assessments, and the project team's collective knowledge of the study area. The primary stream reaches within the project area can be divided into three segments as shown on Figure 2: 1) Upper Miller Creek, 2) Lower Miller Creek and 3) Mainstem Redwood Creek. Coho are known to be present in all three project area stream segments.

9.1.1 Upper Miller Creek

This stream segment has a higher gradient, more flow, and less human consumptive use than Lower Miller Creek. This reach is fed by Buck Creek (BC1 monitoring site), one of the most consistent dry-season water sources within the study area. According to 2016 flow monitoring results (Appendix A), Buck Creek was the only monitoring site within the study area with continuous flow throughout the monitoring period. Also, an informal field survey of a portion of Upper and Lower Miller Creek stream segments conducted in late September 2016 by the project team confirmed an increase in stream flow beginning at the lower extent of the Upper Miller Creek segment and extending upstream. Based on this observation and that the segment already has a good water source in Buck Creek, projects designed to measurably increase flows in this reach should have a significant benefit to aquatic and riparian habitat.

9.1.2 Lower Miller Creek

This stream segment appears to have high quality instream habitat in terms of low channel gradient and large wood presence, but is the most impaired of the three channel segments due to severe dry season low flow conditions. Flow has ceased in the Lower Miller Creek segment for 2 to 4 months each of the last three years, with most pools going completely dry as well. The Lower Miller Creek valley bottom appears to be comprised of coarse alluvium (i.e., sand and gravel) that allows streamflow to drain from the channel as dry conditions persist and the adjacent water table lowers. Impaired low flow conditions are also exacerbated by human consumptive uses. For example, there is at least one near-channel shallow groundwater well in Lower Miller Creek, and Briceland Municipal sources its water from a spring at the head of one of the primary tributaries that feeds Lower Miller Creek (Figure 2). As such, it will likely require large-scale flow enhancement actions to measurably increase dry season flows in Lower Miller Creek.

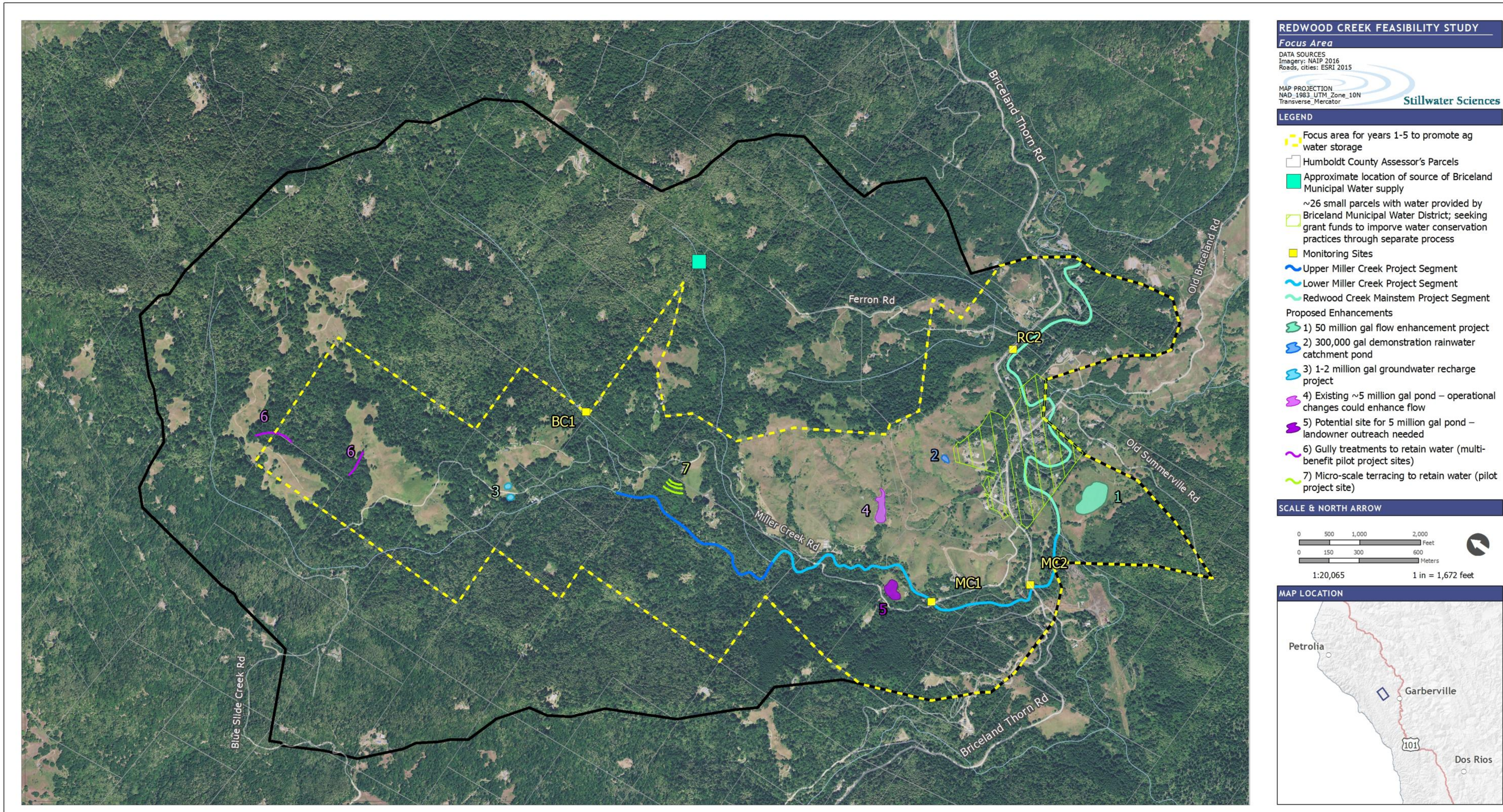


Figure 2. Ten-year plan and reach scale conceptual design.

9.1.3 Mainstem Redwood Creek

This stream segment flows through the town of Briceland and has been the target of numerous instream habitat enhancement projects. In addition to being fed by Miller Creek, this segment also receives flow from Upper Redwood Creek, China Creek, Dinner Creek and Somerville Creek. Flows in this reach have ceased for at least several weeks each of the past three years. Based on the duration of measured zero flow periods (Appendix A), however, this segment is less impaired by low flow conditions than Lower Miller Creek. Pools are more persistent in this reach than in Lower Miller Creek (project team observations) likely due to bedrock sills that prevent the water table from dropping too far beneath the channel bottom. Although the majority of the landholdings adjacent to this stream segment are supplied water by Briceland Municipal, numerous landowners pump water from the stream channel.

9.2 10-year Plan and Reach-scale Conceptual Designs

The 10-year Plan is depicted on Figure 2 and described below. The flow enhancement opportunities discussed herein represent the suite of project types described previously in this report. Targeted field assessments conducted during this project have identified several viable large-volume flow enhancement opportunities within the study area. Project viability is constrained by the following physical conditions:

- Gentle topography: slope of less than 10% with flatter terrain being the most conducive to successful projects, it is critical that slopes in the vicinity of a proposed site are stable and lack any evidence of prior landsliding.
- Grassland or shrub ground cover: although the presence of trees doesn’t entirely preclude large flow enhancement projects, grasslands offer significantly better opportunities because a large amount of tree clearing is not required.
- Proximity to streams: the most ideal sites are located adjacent to stream channels on elevated terraces above 100-year flood elevations, although certain in-stream sites (especially if already in existence) may also be effective while minimizing negative impacts.

Pilot projects for smaller-scale groundwater recharge actions, including gully and terrace/pond treatments, are shown on Figure 2 as projects that could be implemented and monitored to provide proof of concept. Although conceptually viable, to date there is little data showing that these types of treatments individually result in significantly improved flows during the dry season. However, if implemented in large enough number over a broad enough area, these projects could have a cumulative measurable effect on streamflow; and they may be the only action suitable for large areas of the steep and forested upper watershed. If proven successful, it is recommended that additional field assessments are conducted to identify suitable locations to implement these types of projects.

A final critical component of the 10-year plan is providing support for landowners to increase storage and improve water conservation practices as discussed in Section 9.2.3 below.

9.2.1 Prioritization framework

Six factors were used to prioritize different flow enhancement actions, including: 1) the quantity of expected flow increase, 2) probabitlity that a flow increase will be realized along a significant length of stream channel, 3) value of instream habitat experiencing flow increases, 4) cost of implementation actions, 5) potential for community outreach and education beyond the project boundaries, and 6) willing landowner participation. Each project was ranked from 1 (highest) to 3 (lowest) for each of the six factors. Prioritization results are summarized in Table 4.

Table 4. Prioritization framework for flow enhancement actions.

Site-specific action	Flow Increase Rating	Certainty of Flow Increase Rating	Habitat Value Rating	Cost Rating	Community Outreach Rating	Certainty of Landowner Participation Rating	Total Priority Rating
50 million gallon off-channel pond	3	3	2	1	1	3	15
300,000 gallon rainwater catchment pond	1	1	2	3	3	3	13
1 to 2 million gallon groundwater recharge ponds	2	2	2	2	2	2	12
Operational changes to existing ~5 million gallon on channel pond	2	1	3	2	1	1	11
Gully treatments and shallow terrace ponds	1	1	2	2	2	3	11
5 million gallon off-channel pond	2	1	3	1	1	1	9
System Improvements for Briceland Municipal	1	1	3	1	2	1	9

All of the projects listed on Table 4 are considered potentially feasible and ultimately necessary to significantly improve dry season flows throughout the study area. The prioritization framework provides a ranking system to focus resources on those projects believed to be the most beneficial in the near-term.

9.2.2 Site-specific actions

Site-specific actions are summarized in Table 5 below. Stillwater Sciences recommends seeking grant funding as soon as possible to begin work on the top three priority actions described in the first three rows of the table.

Table 5. Summary of site-specific actions.

Site-specific action	Description	Priority	Benefit[5]	Next steps	Schedule
50 million gallon off-channel pond	Two-staged water storage and infiltration system with large pond that feeds groundwater infiltration galleries adjacent to Redwood Creek mainstem; see conceptual design in Appendix C	1	~0.36 cubic feet per second (162 gallons per minute) flow increase on Redwood Creek mainstem during 5-month dry season	Seek funds for full feasibility study and 100% design	2017: secure funding for design 2018-19 design/permitting 2020: implementation
300,000 gallon rainwater catchment pond	Demonstration project for prototype agricultural pond to be used for irrigation and fire suppression; see conceptual design in Appendix C	2	Flow benefits from specific pond difficult to measure, strong benefit in terms of promoting landowner water storage for irrigation which is critical	Seek funds for 100% design and construction	2017: secure funding for design 2018-19 design/permitting 2020: implementation
1 to 2 million gallon groundwater recharge ponds	Medium scale groundwater recharge project in upper portion of Miller Creek watershed	3	3 to 6 gallons per minute flow increase along Upper Miller Creek during 5-month dry season	Seek funds for full feasibility study and 100% design	2017: secure funding for design 2018-19 design/permitting 2020: implementation
Operational changes to existing ~5 million gallon on channel pond	Some pond water is likely used for irrigation supply, but a large portion of the water is potentially available for flow enhancement	4	~16 gallons per minute flow increase in lower Miller Creek during 5-month dry season	Landowner outreach; complicated due to recent CDFW enforcement action; need a water rights strategy because pond is on-channel	2017-18: outreach; 2019-21 planning/design/ permitting; 2022-23: implementation

[5] Flow benefit determined using volumetric calculation converting storage volume to continuous flow over a five month period; assumes 30% evaporation loss.

Site-specific action	Description	Priority	Benefit[5]	Next steps	Schedule
Gully treatments and shallow terrace ponds	Plugging gullies and constructing shallow terrace ponds on gentle slopes to slow and sink runoff into the ground	4	Flow benefits difficult to measure from implementation at one site; additional benefits in terms of sediment reduction; need proof of concept	Seek funds for 100% design, construction, and monitoring (lower priority)	Wait on input from TAC and results from projects outside of study area (Mattole)
5 million gallon off-channel pond	Site location with high potential, but only have secured landowner access on small portion of the site	5	~16 gallons per minute flow increase in lower Miller Creek during 5-month dry season	Additional landowner outreach needed, absentee landowner	2017-18: outreach; 2019-21 planning/design/ permitting; 2022-23: implementation
System Improvements for Briceland Municipal	Currently the largest single water user within the study area, water is supplied for approximately 26 residents	5	Water efficiency, operation changes, and increased storage could have measureable impact on flows	Briceland Municipal in partnership with Trout Unlimited applied for WCB Prop 1 planning funds	Separate planning process; implementation activities and schedule TBD

9.2.3 General landowner outreach activities

Widespread human consumptive use within the study area necessitates a combination of water conservation, storage, and direct flow enhancement by landowners on individual properties to significantly increase dry season flows. Landowner outreach and technical support will therefore be a focus over the next five years in the portion of the study area delineated by the dashed yellow line in Figure 2 . Encouraging water conservation practices that reduce domestic use and create sufficient water storage that provides for both consumptive water use and flow enhancement objectives during the dry season will require outreach and technical support to all landowners within this area. After outreach efforts have been conducted in this priority area, the remaining parts of the study area should be the focus of ongoing outreach. The 300,000-gallon demonstration rainwater catchment pond proposed for Beginnings Inc. (local school) in Briceland will be an excellent opportunity for education and outreach by providing a model for the design, construction, operation, and benefits of rainwater catchments ponds.

9.3 Site-specific Conceptual Designs

Appendix C includes conceptual designs for a 50-million-gallon flow enhancement project adjacent to the right bank of Redwood Creek near Briceland and a 300,000 gallon demonstration rainwater catchment pond at Beginnings Inc. in Briceland. The 50-million-gallon flow enhancement project alone could offset all of the human consumptive use within the study area (estimated at approximately 12 million gallons). The physical characteristics of the site combined with enthusiastic landowner support for the project offer excellent potential. Additional hydrologic and geotechnical analyses are needed to develop a more detailed design for the site (refer to Sheet 1 of the conceptual design drawings in Appendix C). The 300,000 gallon demonstration rainwater catchment pond proposed for Beginnings would provide more modest flow enhancement benefits while also providing a demonstration project for the community.

In addition to these two projects, the 1-2 million gallons groundwater recharge project in upper Miller Creek is also a high priority project that would directly benefit critical aquatic habitat in Miller Creek. This project would provide an additional 3 to 6 gallons per minute of flow to Upper Miller Creek, which considering the small size of the creek channel, could significantly improve conditions for juvenile rearing.

10 CONCLUSION

In addition to increasing human consumptive use throughout north coastal California watersheds, other land uses (e.g., legacy roads and industrial timber harvest), changes in forest vegetation cover, and climate change have exacerbated severely low baseflow conditions during the dry season (refer to Appendix A). To offset these effects, a flow enhancement strategy for the feasibility study area and the greater Redwood Creek watershed must consider widespread small-scale storage and forbearance on individual properties, as well as large-scale storage ponds that recharge groundwater and/or provide a sufficient volume of high quality water to directly enhance streamflows. A strategy involving these approaches leverages both individual private investment in water storage and larger volume and more expensive flow enhancement actions supported by the technical and financial resources of state and federal agencies. As the strategy is implemented, the benefits of grant funded flow enhancement projects will be maintained and improved over time as more upstream and downstream landowners have sufficient water storage to serve their needs during the dry season.

Appendices

Appendix A

Target Flow Technical Memorandum

Appendix B

Miller Creek Residential Water Use Survey

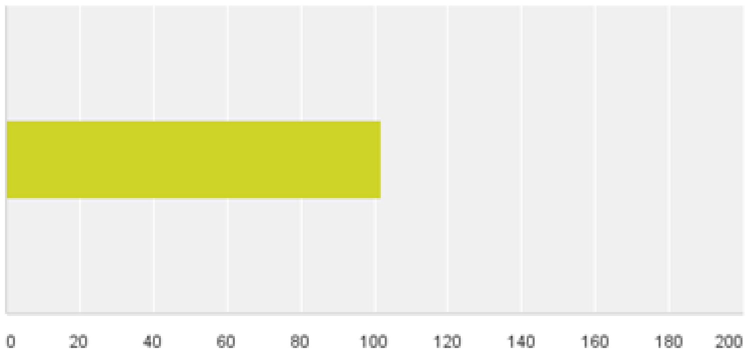
Miller Creek Residential Water Use Survey

June 2016

Evaluation Summary

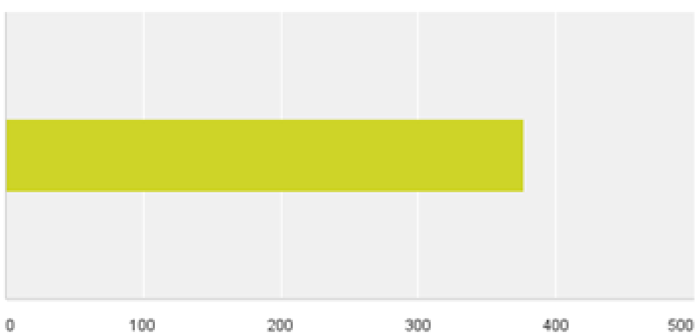
Evaluation Method: Mailed survey questionnaire
Number of Survey Recipients: 100
Number of Survey Respondents: 13
Response Rate: 13%

1. What is your estimated daily water use for domestic (i.e. household) purposes) in gallons?



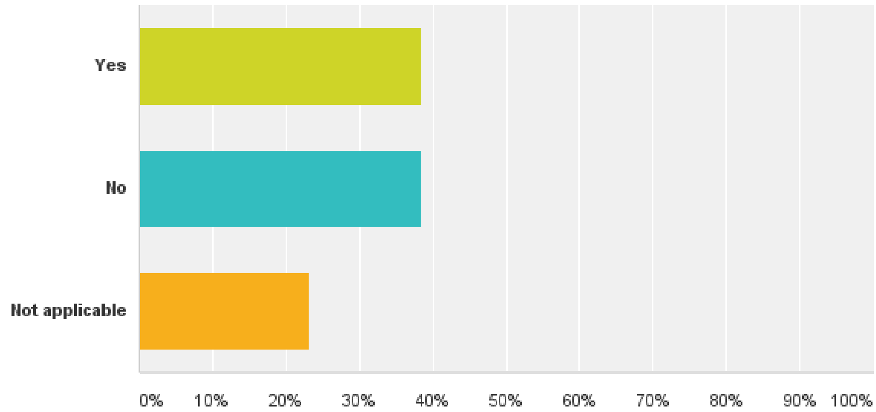
Average:	107
Median:	100
Minimum:	0
Maximum:	300
Total responses:	13

2. What is your estimated daily water use for irrigation (i.e. garden) purposes? in gallons



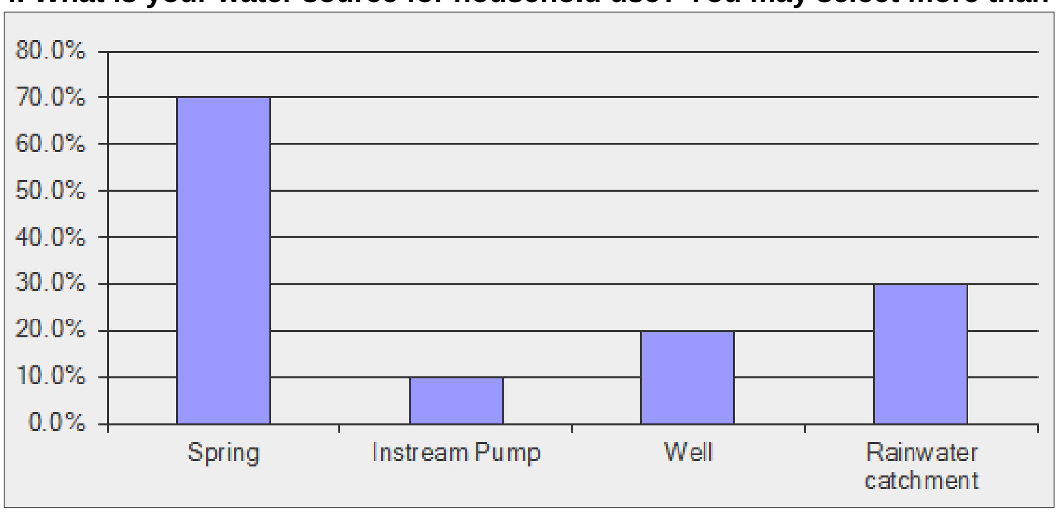
Average:	376
Median:	51
Minimum:	0
Maximum:	1500
Total responses:	11

3. Do you have separate water systems for irrigation and domestic use?



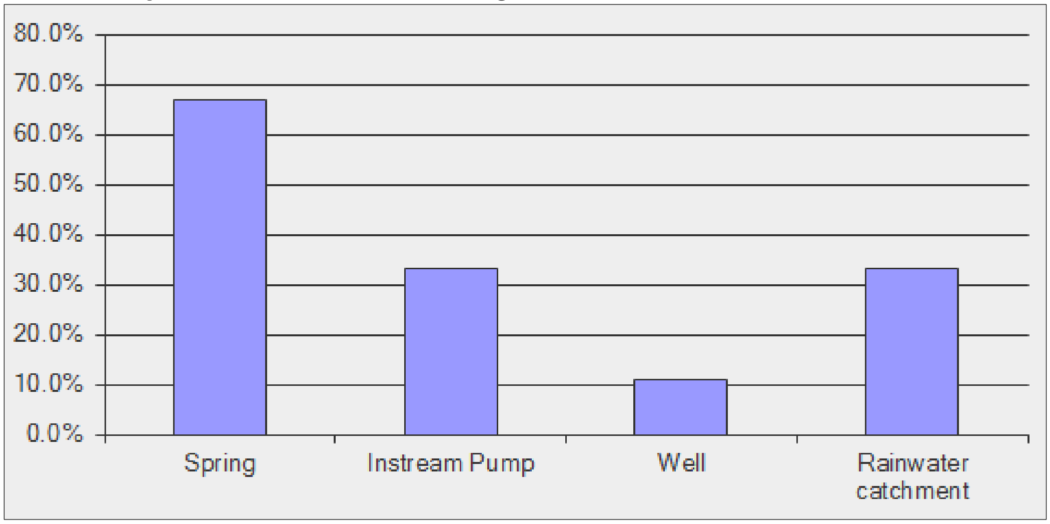
Answer Options	Response Percent	Response Count
Yes	38.46%	5
No	38.46%	5
Not applicable	23.08%	3
Comments		0
answered question		13
skipped question		0

4. What is your water source for household use? You may select more than one.



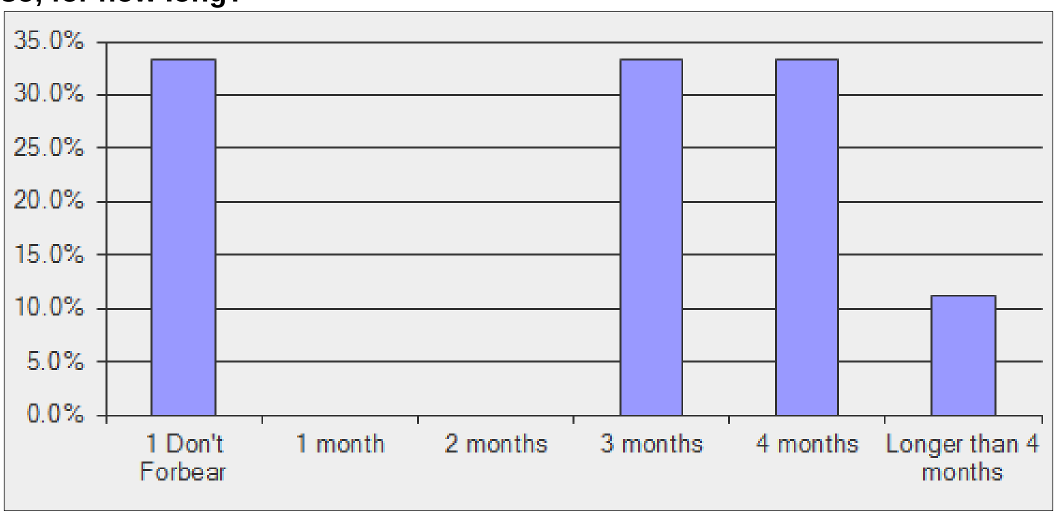
Answer Options	Response Percent	Response Count
Spring	70%	7
Instream Pump	10%	1
Well	20%	2
Rainwater catchment	30%	3
Other		4
answered question		10
skipped question		3

5. What is your water source for irrigation?



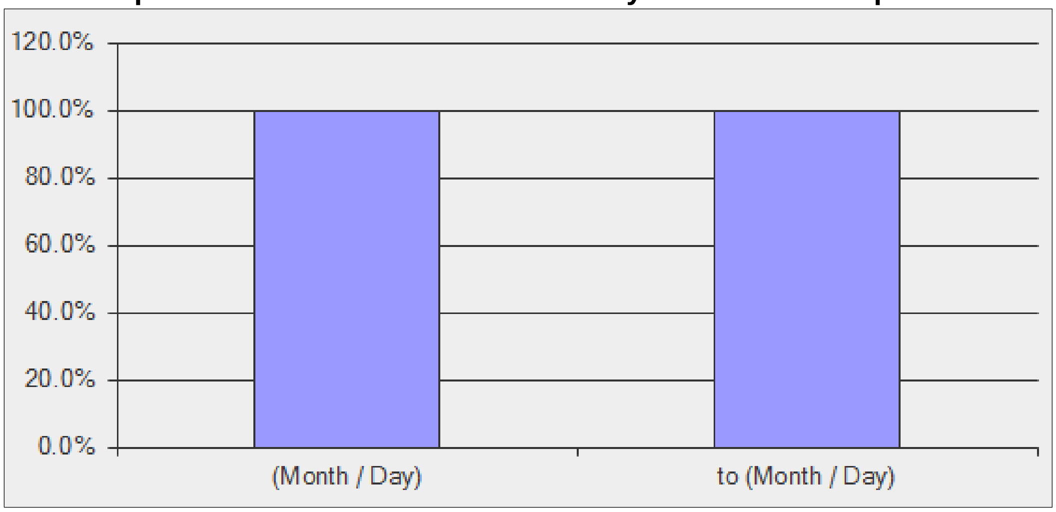
Answer Options	Response Percent	Response Count
Spring	66.7%	6
Instream Pump	33.3%	3
Well	11.1%	1
Rainwater catchment	33.3%	3
Other		5
answered question		9
skipped question		4

6. Do you forbear from pumping or spring diversion for part of the summer and/or fall? If so, for how long?



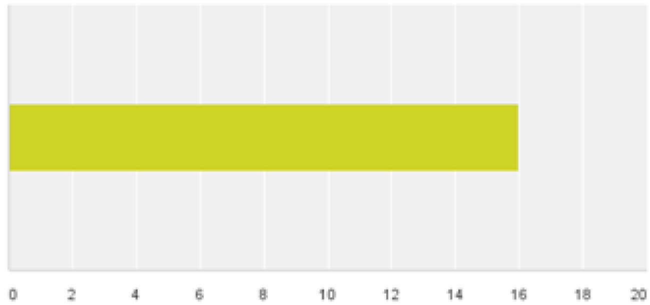
Answer Options	Response Percent	Response Count
1 Don't Forbear	33.3%	3
1 month	0.0%	0
2 months	0.0%	0
3 months	33.3%	3
4 months	33.3%	3
Longer than 4 months	11.1%	1
Other		4
answered question		9
skipped question		4

7. Please provide an estimate of the dates of your forbearance period:



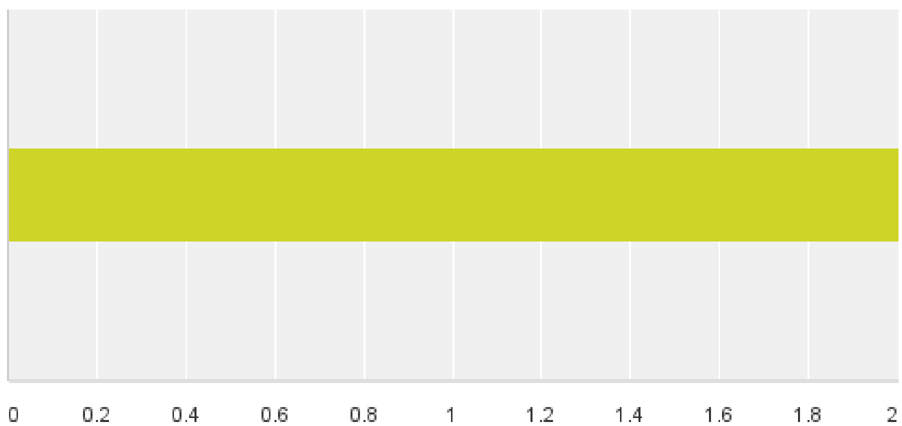
Answer Options	Response Percent	Response Count
(Month / Day)	100.0%	7
to (Month / Day)	100.0%	7
answered question		7
skipped question		6

8. If you pump from a well or creek, what is your pumping rate in Gallons Per Minute (GPM)? Leave this question blank if you do not pump from a well or a creek.



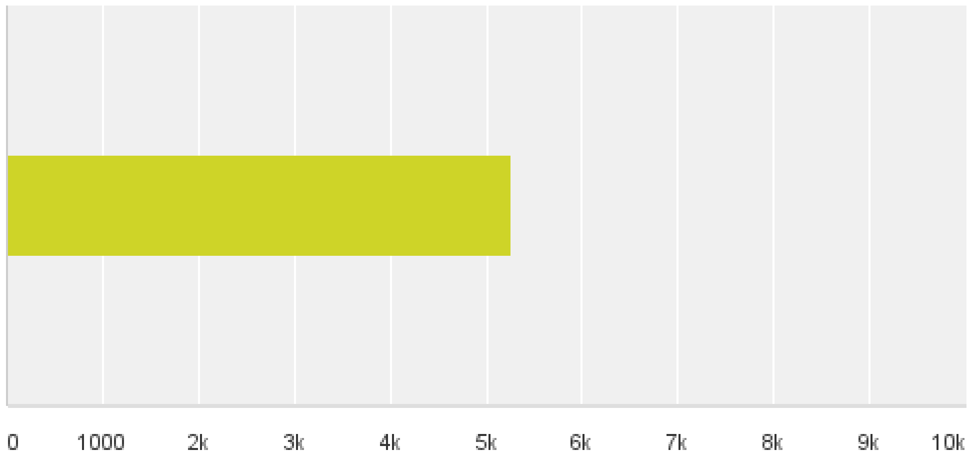
Number of responses: 2
Individuation responses: 12 & 20

9. How many hours per day do you pump?



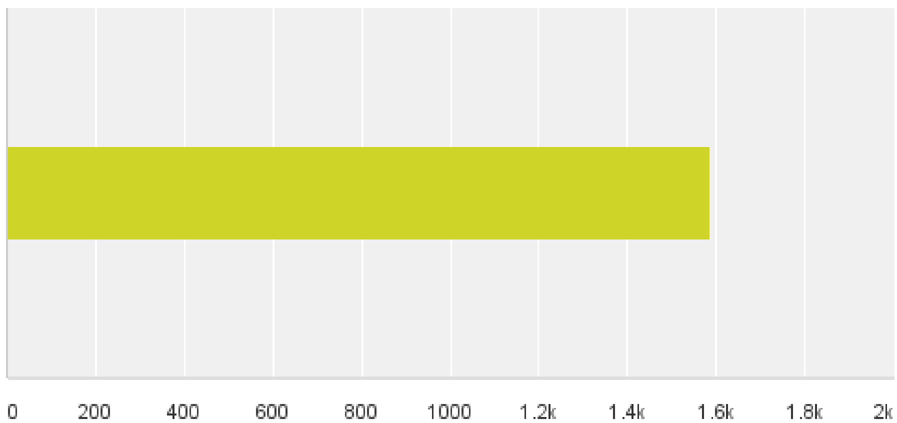
Average:	2
Median:	1
Minimum:	1
Maximum:	6
Total responses:	5

10. If you get water from a spring, what is your average flow rate (in Gallons Per Day) in May? Leave this question blank if you do not get your water from a spring.



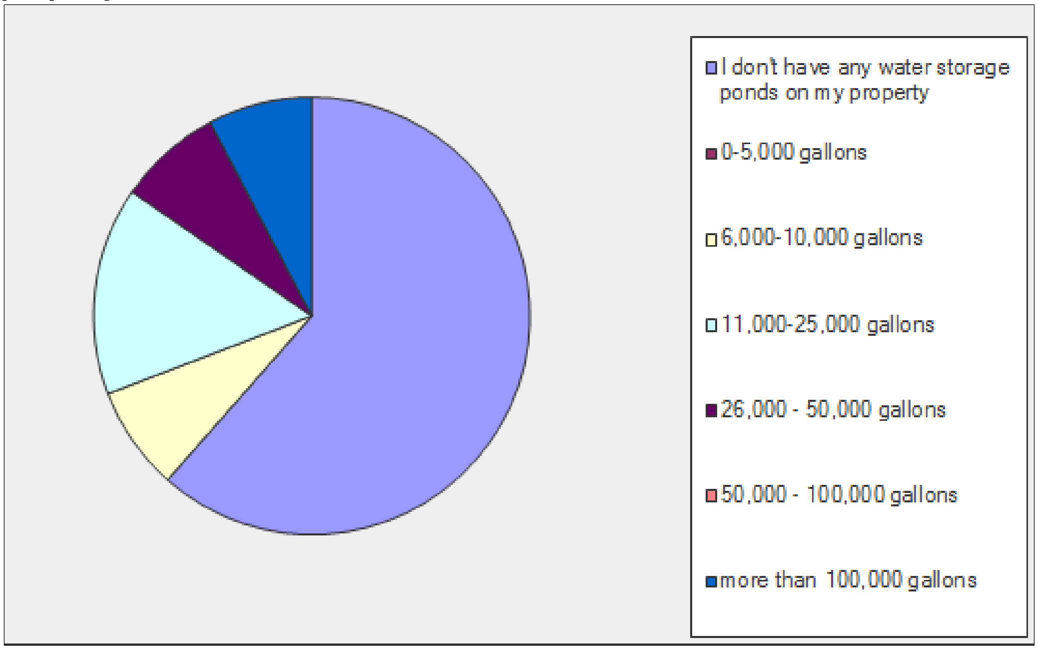
Average:	5260
Median:	1156
Minimum:	4
Maximum:	28000
Total responses:	7

11. If you get water from a spring, what is your average flow rate (in Gallons Per Day) in September? Leave this question blank if you do not get your water from a spring.



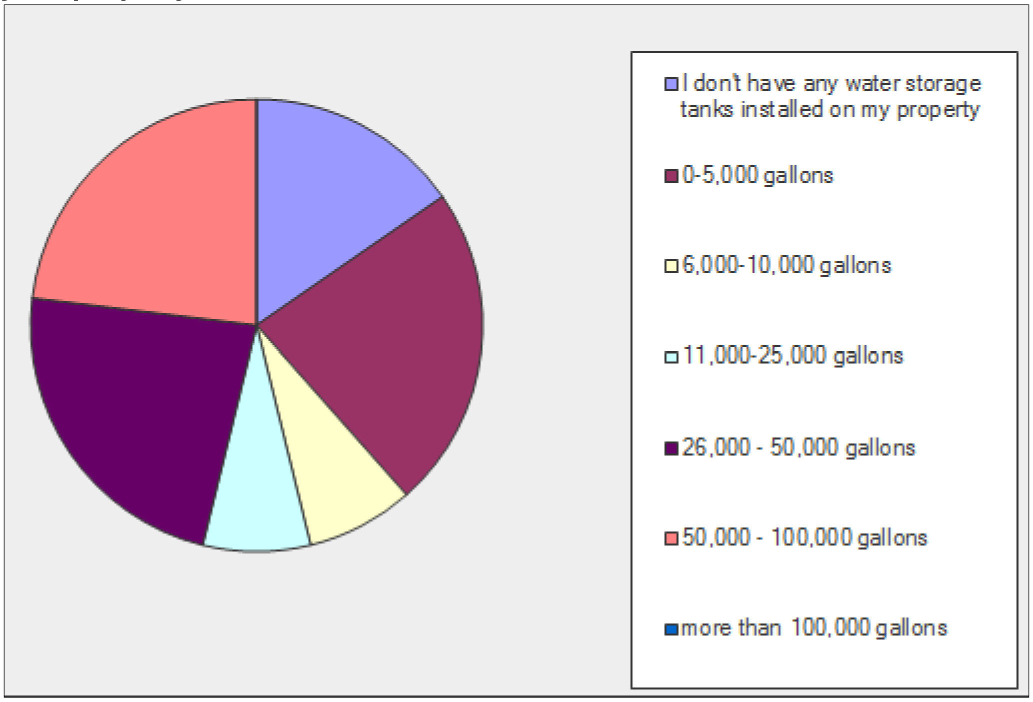
Average:	1587
Median:	2
Minimum:	0
Maximum:	11000
Total responses:	7

12. Please indicate how much water storage (in ponds) you currently have on your property.



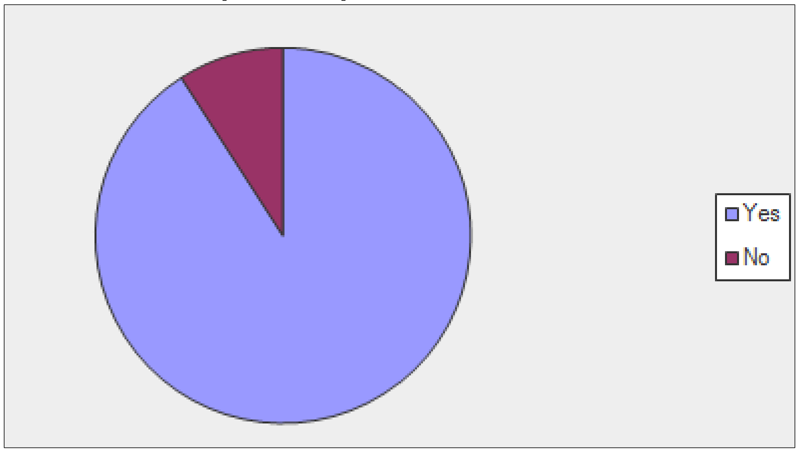
Answer Options	Response Percent	Response Count
I don't have any water storage ponds on my property	61.5%	8
0-5,000 gallons	0.0%	0
6,000-10,000 gallons	7.7%	1
11,000-25,000 gallons	15.4%	2
26,000 - 50,000 gallons	7.7%	1
50,000 - 100,000 gallons	0.0%	0
more than 100,000 gallons	7.7%	1
Other (please specify)		0
answered question		13
skipped question		0

13. Please indicate how much water storage (in tanks) you currently have installed on your property.



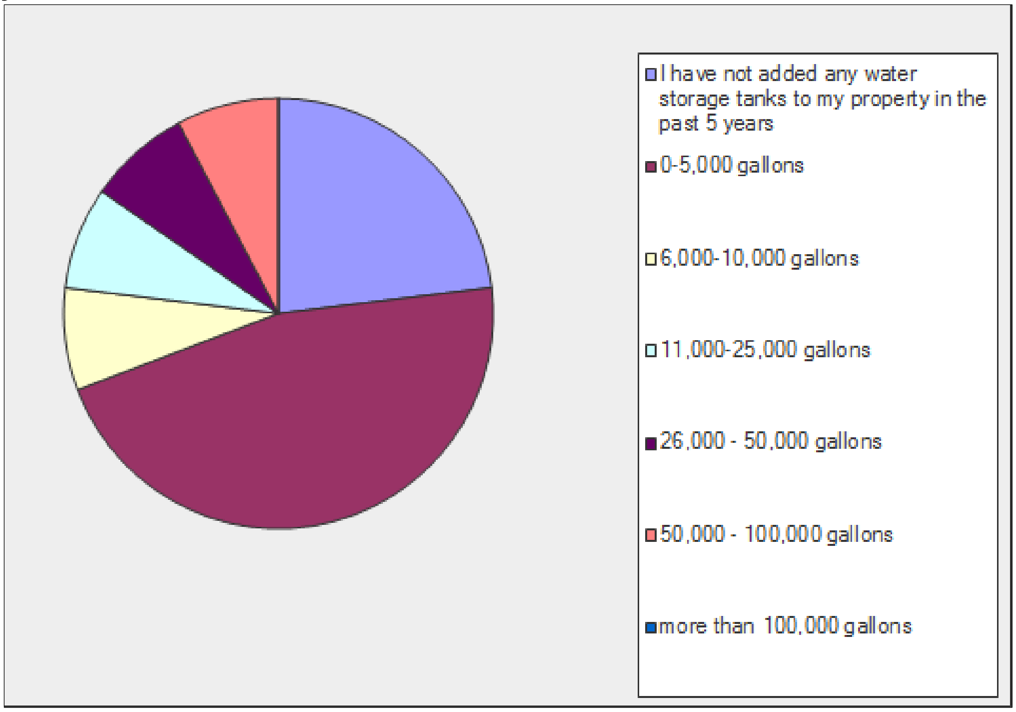
Answer Options	Response Percent	Response Count
I don't have any water storage tanks installed on my property	15.4%	2
0-5,000 gallons	23.1%	3
6,000-10,000 gallons	7.7%	1
11,000-25,000 gallons	7.7%	1
26,000 - 50,000 gallons	23.1%	3
50,000 - 100,000 gallons	23.1%	3
more than 100,000 gallons	0.0%	0
Other (please specify) ______gallons		0
answered question		13
skipped question		0

14. If your household does use one or more water storage tanks, do you have any mechanisms in place to prevent tank overflows?



Answer Options	Response Percent	Response Count
Yes	90.9%	10
No	9.1%	1
If yes, do you have float valves on the supply lines to your tanks or is the overflow plumbed to a creek? If no, please tell us why your household does not use mechanisms to prevent tank overflows (example: concern about economic costs):		9
answered question		11
skipped question		2

15. How many gallons of water storage have you added to your property in the past 5 years?



Answer Options	Response Percent	Response Count
I have not added any water storage tanks to my property in the past 5 years	23.1%	3
0-5,000 gallons	46.2%	6
6,000-10,000 gallons	7.7%	1
11,000-25,000 gallons	7.7%	1
26,000 - 50,000 gallons	7.7%	1
50,000 - 100,000 gallons	7.7%	1
more than 100,000 gallons	0.0%	0
Other (please specify)		0
answered question		13
skipped question		0

Appendix C

Flow Enhancement Conceptual Designs