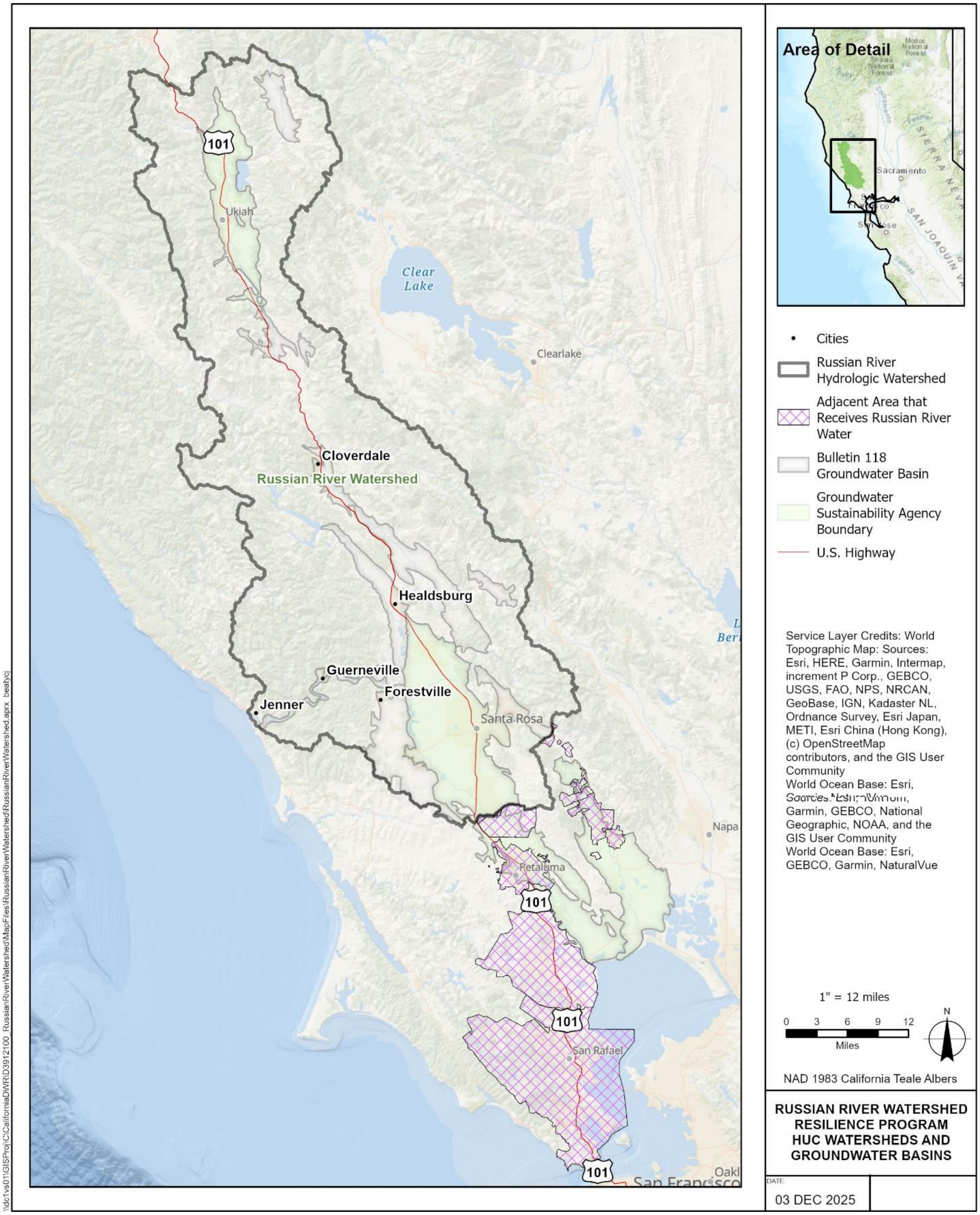
Draft Russian River Watershed Historical Water Budget Memorandum

Russian River Watershed Resilience Plan
Draft December 2025

1. Purpose and Scope

This technical memorandum (TM) highlights the development of historical water budgets to support the Russian River Watershed Resilience Pilot (RRWRP). **Figure 1** shows the study area for the RRWRP, which encompasses the entirety of the Russian River watershed as well as additional Sonoma Water service areas where Russian River water supplies play a significant role in meeting urban water demands and helps to offset groundwater pumping in these areas. The RRWRP study area includes the entire Russian River watershed, including its groundwater basins, and includes important hydrological features such as Lake Mendocino and Lake Sonoma; Potter Valley, Ukiah Valley, Santa Rosa Plain, and Alexander Valley groundwater basins; and the Laguna de Santa Rosa and Russian River Estuary. The adjacent areas that receive Russian River water encompass portions of the North Bay watershed (i.e., Sonoma Water service areas) including Sonoma Valley and Petaluma Valley groundwater basins, and Sonoma Water service areas in Petaluma, Valley of the Moon, Sonoma, Novato, and San Rafael. Including the “plus” area expansion ensures that the hydrologic and hydrogeologic conditions of the Russian River watershed that affect water supply to all relevant communities, infrastructure, and populations are being considered for this effort.

Water budgets presented and discussed in this TM are intended to characterize inflow, outflow, and net flux terms associated with surface water, land surface, and groundwater systems. Evaluation of these water budgets provides a characterization of sources of consumptive use, imports, exports, and distribution of flows throughout the RRWRP study area that affect water supply throughout the Russian River. Water budgets are compiled from various sources, supported by guidance from the Handbook for Water Budget Development (DWR 2020). The following sections of this TM will discuss the data sources used to develop historical water budgets for the RRWRP study area, will describe the water budget structure devised from these data sources, and will present and discuss water budget results.



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RUSSIAN RIVER WATERSHED RESILIENCE PROGRAM HUC WATERSHEDS AND GROUNDWATER BASINS

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Figure 1. Proposed Russian River Watershed Resilience Pilot Study Area

2. Data Sources

The following section describes the key sources of information used to develop historical water budgets for the RRWRP study area. For the purposes of this TM, two sources were used to develop water budgets: 1) GSFLOW model of the Russian River Watershed, and 2) Groundwater Sustainability Plans (GSPs) for Santa Rosa Plain, Petaluma Valley, and Sonoma Valley. The following sections will describe these sources in more detail.

2.1 Russian River Watershed GSFLOW Model

Water budgets for the Russian River watershed were estimated using a newly developed integrated modeling framework (The Russian River Watershed GSFLOW Model; Adera et al., *in review*) which simulates hydrologic surface and groundwater processes (GSFLOW; Markstrom and others 2008) by coupling groundwater processes using MODFLOW-NWT (Niswonger and others 2005) and landscape and watershed processes using PRMS (Markstrom and others 2015). Additionally, the Russian River Watershed GSFLOW Model simulates irrigation water demands using the Agricultural water use (AG) package (Niswonger 2020), reservoir operations, diversions, and conjunctive use using a linked-flow network model (MODSIM; Labadie 2005). The Russian River Watershed GSFLOW Model and MODSIM are strongly coupled to ensure water balance and convergence of both the simulated hydrologic and optimal water allocation problems. The AG package represents irrigation water demands by simulating evaporative demand associated with temperature and precipitation. The model dynamically simulates irrigation demand, dependent on agricultural field soil-water balance, to simulate changes in crop water requirements and their partitioning into effective precipitation and irrigation (Niswonger 2020; **Figure 2**). Irrigation is calculated by the model using dynamic agricultural demands calculated by the Russian River Watershed GSFLOW Model that are then passed to MODSIM for determining reservoir operations and irrigation withdrawals. Irrigation withdrawals can then be stored in ponds for later use which is an important dynamic for determining irrigation water requirements and subsequent groundwater pumping to meet these requirements. Publication of the USGS modeling study and public release of the attendant modeling tools is anticipated in late 2025.

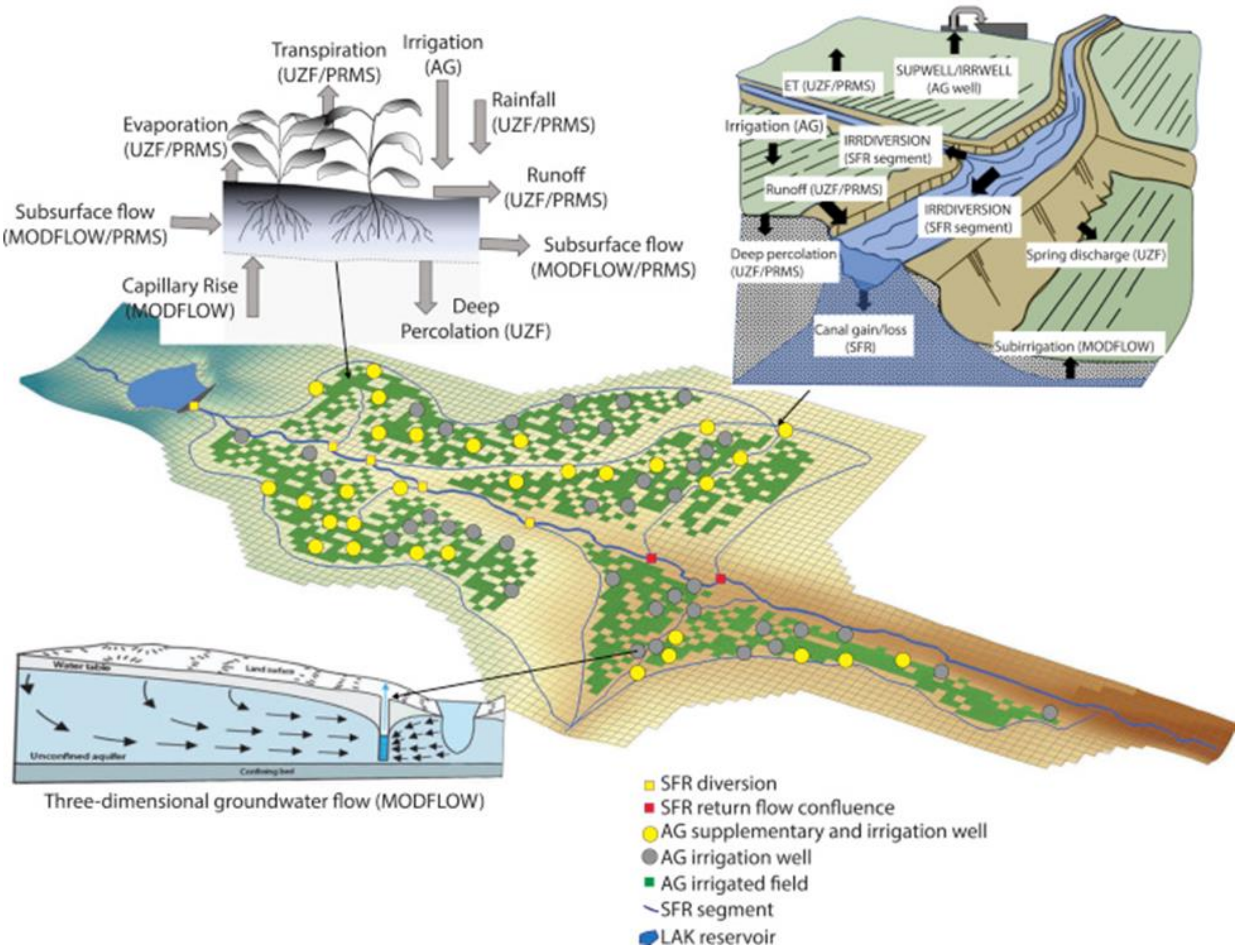

Figure 2. Illustration showing how the Agricultural Water Use Package represents agricultural processes in MDOFLW, PRMS, and GSFLOW (from Niswonger, 2020)

2.2 Groundwater Sustainability Plans

The planning area for the RRWRP includes four areas in which GSPs have been developed as part of the California Sustainable Groundwater Management Act (SGMA). These groundwater basins include the Santa Rosa Plain, Petaluma Valley, Sonoma Valley, and Ukiah Valley basins (Figure 1). The passage of SGMA in 2014 required formation of local Groundwater Sustainability Agencies (GSAs) in high and medium priority groundwater basins. SGMA required the GSAs to develop GSPs that characterize groundwater conditions within the basins and outline steps to achieve groundwater sustainability by 2040. The four GSPs developed for groundwater basins within the RRWRP planning area were submitted in 2020. The GSPs were required to develop detailed, comprehensive water budgets, per SGMA guidelines. These water budgets are referenced here for the GSA areas that fall within the RRWRP planning area and outside of the Russian River Watershed GSFLOW Model domain.

To support water budget development and historical assessment of hydrologic conditions for the RRWRP, GSPs for the Santa Rosa Plain, Petaluma Valley, and Sonoma Valley groundwater subbasins were utilized to characterize water budget terms in these three subareas. At the time of development of this document, the integrated groundwater flow models used to support the development of these GSPs were under further development to support required periodic evaluations under SGMA and were not available for further simulation runs, water budget reporting, and evaluation of hydrologic conditions. Thus, reporting of water budget information from these three GSPs is intended to supplement and support the water budgets derived from the Russian River Watershed GSFLOW Model to further characterize hydrologic conditions in nearby regions not included within the extent of the Russian River Watershed GSFLOW

Model. Assumptions inherent to the water budget terms from the Russian River Watershed GSFLOW Model may not be consistent with those used to develop budgets for the GSPs, making direct intercomparison and/or combination of like budget terms across different modeling tools challenging, and potentially resulting in misguided evaluation of hydrologic conditions for the RRWRP.

Table 1 provides an overview of the integrated groundwater flow models used to support water budget development and the historical water budget period summarized for the Santa Rosa Plain, Petaluma Valley, and Sonoma Valley GSPs. Historical water budgets are presented in detail for each groundwater subbasin in Section 3 – Basin Setting of each GSP. In subsequent sections of this TM, high-level summaries of the water budgets, as presented in the GSP, are provided; however, readers should refer to the full Section 3 report of each GSP for full detail on the development, presentation, and summary of water budgets.

Water budgets for the Ukiah Valley GSA area were developed as part of the Ukiah Valley Basin GSP; however, because the GSA area overlaps with the Russian River Watershed GSFLOW Model, results from the GSP were not used to develop water budgets for the RRWRP. Instead, water budgets from the Russian River Watershed GSFLOW Model are presented here for consistency throughout the Russian River watershed.

Table 1. Groundwater Models and Historical Time Periods used in GSP Water Budget Development

Groundwater Subbasin	Groundwater Model used to Support Water Budget Development	Historical Water Budget Time Period
Santa Rosa Plain	▪ Santa Rosa Plain Hydrologic Model (SRPHM) ▪ Originally developed by U.S. Geological Survey (USGS) (Woolfenden and Nishikawa 2014) and updated by the UGSS and Sonoma Water to support GSP water budget development (Alzairee and others 2025).	▪ Water Year (WY) 1976 to 2018
Petaluma Valley	▪ Petaluma Valley Integrated Groundwater Flow Model (PVIHM) ▪ Developed by the USGS in conjunction with Sonoma Water (citation forthcoming)	▪ WY 1969 through 2018
Sonoma Valley	▪ Sonoma Valley Integrated Groundwater Flow Model Version 2 (SVIGFM v2) ▪ SVIGFM was developed by Sonoma Water (Sonoma Water 2020a and 2020b)	▪ WY 1971 through WY 2018

Note:

Santa Rosa Plain GSP – Section 3: Basin Setting

Petaluma Valley GSP – Section 3: Basin Setting

Sonoma Valley GSP – Section 3: Basin Setting

3. Water Budget Structure

3.1 Water Budget Control Volumes

The following sections describe the water budget control volumes used to create water budgets for the Russian River Watershed and Santa Rosa Plain, Sonoma Valley, and Petaluma Valley groundwater subbasins.

3.1.1 Russian River Watershed GSFLOW Model

Water budgets were estimated for 22 hydrologic subbasins in the Russian River watershed using the Russian River Watershed GSFLOW Model. Water budgets were developed for each subbasin using a combination of outputs from various components of the Russian River Watershed GSFLOW Model, including MODFLOW, PRMS, and GSFLOW AG Package. For this study, the 22 subbasins have been aggregated into four larger Water Budget Areas (WBAs), the Upper Russian River, Alexander Valley, Dry Creek, and the Lower Russian River, as well as a watershed-wide budget (**Figure 3**).

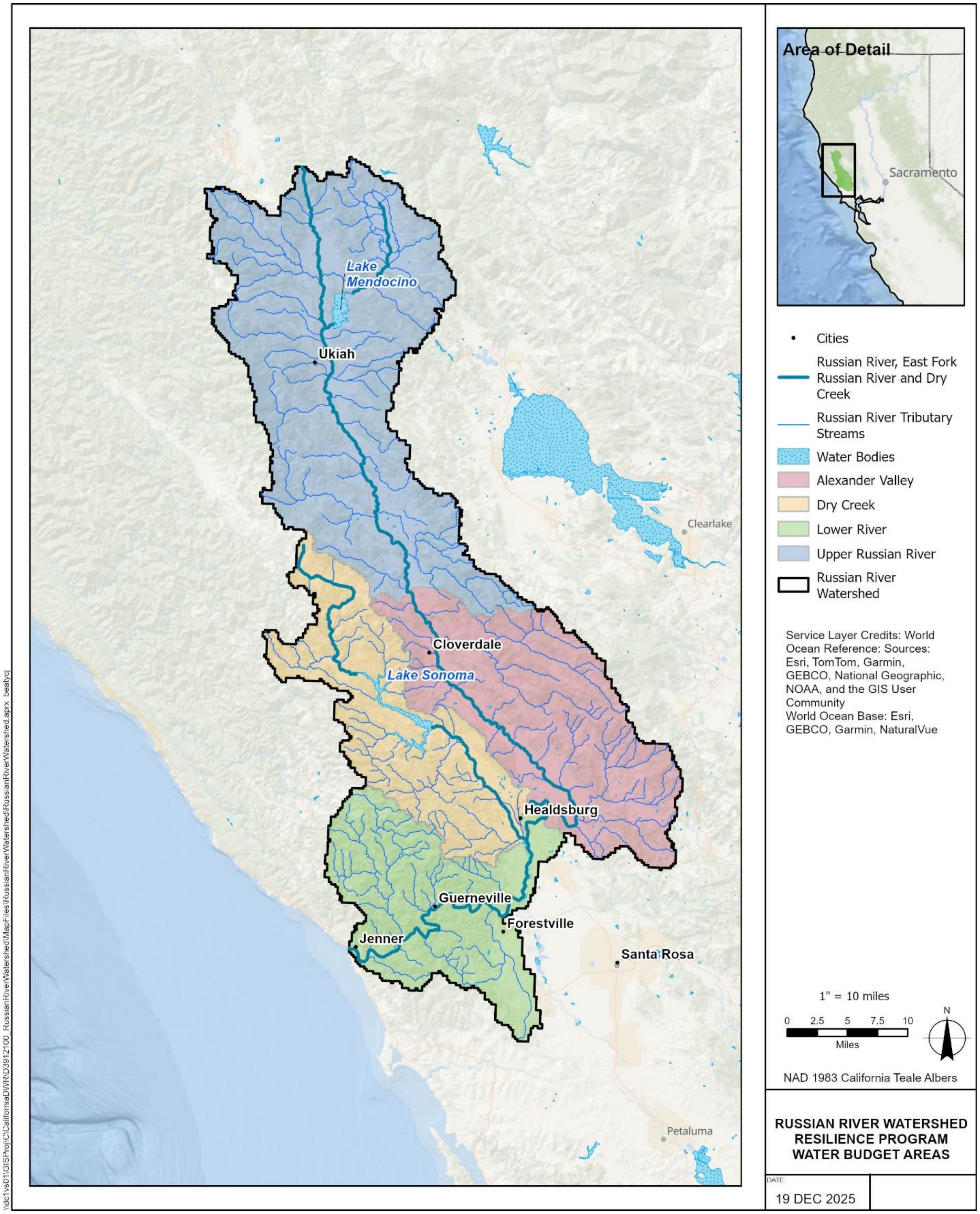

Figure 3: Russian River Watershed Water Budget Areas

3.1.2 Groundwater Sustainability Plans

The water budget control volumes for the Santa Rosa Plain, Petaluma Valley, and Sonoma Valley GSPs are coincident with the GSA boundaries (Figure 1). Descriptions of each control volume are described in detail of Section 3 of the Santa Rosa Plain, Petaluma Valley, and Sonoma Valley GSPs. For the Santa Rosa Plain GSP, a description of the control volume used in development of water budgets is described in Section 3.3 and portrayed in Figures 3-21 and 3-22. For the Petaluma Valley, a description of the control volume used in development of water budgets is described in Section 3.3.1.1 and Figures 3-21 and 3-23. For the Sonoma Valley, a description of the control volume used in development of water budgets is described in Section 3.3.1.1 and Figures 3-25 and 3-27.

3.2 Surface Water System

The following sections describe the structure of the Surface Water System used to develop surface water budgets for the Russian River WBAs, and the Santa Rosa Plain, Petaluma Valley, and Sonoma Valley subbasins.

3.2.1 Russian River Watershed

The Russian River Watershed GSFLOW Model simulates surface water as a system of stream networks and lakes. Surface water system budgets for the Russian River watershed are estimated using the following Russian River Watershed GSFLOW Model outputs given in **Table 2**. 'Streamflow In' includes flows into the Russian River watershed from the Potter Valley Project (PVP) and Mark West Creek. Contributions from these inflows are reflected in 'Streamflow In' values in the Russian River Surface Water Budget (PVP and Mark West Creek), the Upper Russian River Subbasin (PVP), and the Lower Russian River Subbasin (Mark West Creek).

Table 2: Surface Water system budget components, with the descriptive water budget component name, the model output term (and whether the term is from MODFLOW, PRMS, or the AG package), and whether the component describes an inflow, outflow, or a net flux

Descriptive name	Russian River Watershed GSFLOW Model output	Inflow, outflow, or net flux
Groundwater flux to/from lakes	LAKE SEEPAGE IN - LAKE SEEPAGE OUT (MODFLOW)	Net flux
Groundwater flux to/from streams	STREAM LEAKAGE IN - STREAM LEAKAGE OUT (MODFLOW)	Net flux
Runoff and subsurface interflow to streams	sroff + ssres_flow (PRMS)	Inflow
Runoff and subsurface interflow to lakes	lakein_sz (PRMS)	Inflow
Streamflow in	gage files (MODFLOW)	Inflow
Total agricultural diversions	direct_div + pond_div (Ag package)	Outflow
Streamflow out	gage files (MODFLOW)	Outflow

3.2.2 Santa Rosa Plain Subbasin

As part of GSP development, a surface water budget was developed to characterize the surface water inflows and outflows to the Santa Rosa Plain Subbasin. Refer to Figure 3-22 in the Basin Setting (Section 3) of the Santa Rosa Plain Subbasin GSP for a map displaying an overview of the surface water inflows and outflows that establish the corresponding surface water budget. A list of the inflow and outflow terms associated with surface water budget are provided as follows:

Surface water inflows to Santa Rosa Plain Subbasin include:

- Runoff of precipitation (overland flow)
- Surface water inflows from creeks that enter the Santa Rosa Plain Subbasin: Mark West Creek, Santa Rosa Creek, Laguna de Santa Rosa, Blucher Creek, Windsor Creek, Copeland Creek, and other smaller streams
- Groundwater Discharge to streams

Surface water outflows from Santa Rosa Plain Subbasin include:

- Streambed recharge to groundwater
- Outflow to neighboring subbasins, including:
- Outflow to Mark West Creek and Windsor Creek
- Outflow to Petaluma River and Estero de Santa Antonio to the Petaluma Valley Basin
- Outflow of a combination of other smaller streams
- Evaporation (assumed to be negligible compared to other surface water outflows)
- Direct diversions

All surface water inflows and outflows, except for direct diversions, are simulated and summarized based on the historical simulations of the Santa Rosa Plain Hydrologic Model (SRPHM). Direct diversions from surface water were not directly simulated in SRPHM due to the lack of data accuracy at the time of model development. However, summaries of direct diversions were included based on data from eWRIMs. The results section of this TM will provide a high-level quantitative summary of these surface water inflow and outflow terms.

3.2.3 Petaluma Valley Subbasin

As part of GSP development, a surface water budget was developed to characterize the surface water inflows and outflows to the Petaluma Valley Subbasin. Refer to Figure 3-23 in the Basin Setting (Section 3) of the Petaluma Valley Subbasin GSP for a map displaying an overview of the surface water inflows and outflows that establish the corresponding surface water budget. A list of the inflow and outflow terms associated with surface water budget are provided as follows:

Surface water inflows to Petaluma Valley Subbasin include:

- Runoff – Runoff of precipitation and excess irrigation
- Surface water boundary inflow – Lichau Creek, Willow Brook, Lynch Creek, Adobe Creek, Wiggins Hill Creek, San Antonio Creek, Petaluma River, and combination of all other smaller streams
- Groundwater discharge to streams

Surface water outflows from Petaluma Valley Subbasin include:

- Stream leakage to groundwater
- Surface water boundary outflow
- Evaporation (negligible compared to other surface water outflows)

- Diversions

All surface water inflows and outflows are simulated and summarized based on the historical simulations of the Petaluma Valley Integrated Groundwater Flow Model (PVIHM). The results section of this TM will provide a high-level quantitative summary of these surface water inflow and outflow terms.

3.2.4 Sonoma Valley Subbasin

As part of GSP development, a surface water budget was developed to characterize the surface water inflows and outflows to the Sonoma Valley Subbasin. Refer to Figure 3-27 in the Basin Setting (Section 3) of the Sonoma Valley Subbasin GSP for a map displaying an overview of the surface water inflows and outflows that establish the corresponding surface water budget. A list of the inflow and outflow terms associated with surface water budget are provided as follows:

Surface water inflows to Sonoma Valley Subbasin include:

- Overland flow – Runoff of precipitation and excess irrigation
- Mountain-front runoff – Runoff of precipitation and excess irrigation generated in the mountain-front sub-catchment areas outside of the Subbasin boundary
- Surface water inflow from streams entering the Subbasin – Sonoma Creek, Calabazas Creek, Rodgers Creek, Carriger Creek, Nathanson Creek, Arroyo Seco, combination of all other smaller streams
- Groundwater discharge to streams

Surface water outflows from Sonoma Valley Subbasin include:

- Streambed recharge to groundwater
- Outflow at southern end of Subbasin budget area
- Evaporation (negligible compared to other surface water outflows)
- Surface water diversions from streams

All surface water inflows and outflows are simulated and summarized based on the historical simulations of the Sonoma Valley Integrated Groundwater Flow Model Version 2 (SVIGFM v2). The results section of this TM will provide a high-level quantitative summary of these surface water inflow and outflow terms.

3.3 Land System

The following sections describe the structure of the land system used to develop land system water budgets for the Russian River WBAs, and the Santa Rosa Plain, and Petaluma Valley subbasins. A land system water budget was not presented as part of the Sonoma Valley Subbasin GSP, therefore, a land system water budget is not included in this TM for the Sonoma Valley subbasin.

3.3.1 Russian River Watershed

The Russian River Watershed GSFLOW Model simulates the land system water fluxes using a combination of PRMS, MODFLOW, and the AG Package. Land system budgets for the Russian River watershed are estimated using the following Russian River Watershed GSFLOW Model outputs given in **Table 3**.

Table 3: Land system budget components, with the descriptive water budget component name, the model output term (and whether the term is from MODFLOW, PRMS, or the Ag package), and whether the component describes an inflow, outflow, or a net flux

Descriptive name	Russian River Watershed GSFLOW Model output	Inflow, outflow, or net flux
Agricultural groundwater pumping*	*AG WE OUT* (Ag package)	Inflow
Surface runoff to stream network	*sroff* (PRMS)	Outflow
Total precipitation	*hru_ppt* (PRMS)	Inflow
Evapotranspiration (excluding ET from groundwater)	*hru_actet – GW ET OUT* (PRMS + MODFLOW)	Outflow
Subsurface flow (interflow) to stream network	*ssres_flow* (MODFLOW)	Outflow
Total agricultural diversions*	*direct_div* + *pond_div* (Ag package)	Inflow
recharge	*gage files* (MODFLOW)	Outflow

*NOTE: Agricultural diversions are assumed to be applied at the land surface or in surface ponds

3.3.2 Santa Rosa Plain Subbasin

As part of GSP development, a watershed and soil-zone budget was developed to characterize the land system inflows and outflows to the Santa Rosa Plain Subbasin and the surrounding watersheds that are simulated in SRPHM. Refer to Figure 3-21 in the Basin Setting (Section 3) of the Santa Rosa Plain Subbasin GSP for a map displaying an overview of the watershed water budget areas that establish the corresponding land system water budget. A list of the inflow and outflow terms associated with land system water budget are provided as follows:

Land system inflows to Santa Rosa Plain Subbasin include:

- Agricultural irrigation water added to the soil zone
- Precipitation

Land system outflows from Santa Rosa Plain Subbasin include:

- ET in the soil zone
- Lateral flow of soil water to the stream network (interflow)
- Rejected soil water that flows to the stream network (Dunnian Flow)
- Soil-zone Recharge

In addition to the inflows and outflows from the land system water budget, the SRPHM tracks changes in soil moisture through time.

3.3.3 Petaluma Valley Subbasin

As part of GSP development, a land system water budget was developed to characterize the land system inflows and outflows to the Petaluma Valley Subbasin. Refer to Figure 3-22 in the Basin Setting (Section 3) of the Petaluma Valley GSP for a map displaying the extent of the Petaluma Valley groundwater subbasin which establishes the extent of the reported land system water budget. A list of the inflow and outflow terms associated with land system water budget are provided as follows:

Land system inflows to Petaluma Valley Subbasin include:

- Precipitation
- Surface water deliveries from stream diversions
- Recycled water deliveries
- Groundwater pumpage deliveries

Land system outflows from Petaluma Valley Subbasin include:

- Consumptive uses such as:
- ET of precipitation
- ET of groundwater (phreatic uptake by plant roots)
- ET of irrigation water
- Runoff of precipitation and excess irrigation water
- Deep percolation of precipitation and excess irrigation water

3.3.4 Sonoma Valley Subbasin

No land system water budget presented as part of the Sonoma Valley Subbasin GSP.

3.4 Groundwater System

The following sections describe the structure of the groundwater system used to develop groundwater budgets for the Russian River WBAs, and the Santa Rosa Plain, Petaluma Valley, and Sonoma Valley subbasins.

3.4.1 Russian River Watershed

The Russian River Watershed GSFLOW Model simulates groundwater fluxes using MODFLOW and the Ag Package. Groundwater budgets for the Russian River watershed are estimated using the following Russian River Watershed GSFLOW Model outputs given in **Table 4**.

Table 4: Groundwater budget components, with the descriptive water budget component name, the model output term (and whether the term is from MODFLOW, PRMS, or the Ag package), and whether the component describes an inflow, outflow, or a net flux

Descriptive name	GSFLOW output	Inflow, outflow, or Net flux
Agricultural groundwater pumping	*AG WE OUT* (Ag package)	Outflow
evapotranspiration from groundwater	*GW ET OUT* (MODFLOW)	Outflow

net total boundary groundwater fluxes	*From Other Zones IN - From Other Zones OUT + HEAD DEP BOUNDS IN - HEAD DEP BOUNDS OUT+ CONSTANT HEAD IN - CONSTANT HEAD OUT* (MODFLOW)	Net flux
net groundwater flux to/from lakes	*LAKE SEEPAGE IN - LAKE SEEPAGE OUT* (MODFLOW)	Net flux
municipal and industrial groundwater pumping	*MNW2 OUT* (MODFLOW)	Outflow
net groundwater flux to/from land surface	*SURFACE LEAKAGE IN - SURFACE LEAKAGE OUT* (MODFLOW)	Net flux
net groundwater flux to/from stream network	STREAM LEAKAGE IN - STREAM LEAKAGE OUT (MODFLOW)	Net flux
recharge	*Recharge* (MODFLOW)	Inflow
rural domestic groundwater pumping	*WELLS OUT* (MODFLOW)	Outflow
storage*	*STORAGE IN - STORAGE OUT* (MODFLOW)	Net flux

* NOTE: Positive storage values indicate the volume of water that is released from groundwater storage. Negative storage values indicate the volume of water that is partitioned into groundwater storage

3.4.2 Santa Rosa Plain Subbasin

As part of GSP development, a groundwater budget was developed to characterize the groundwater inflows and outflows to the Santa Rosa Plain Subbasin. Refer to Figure 3-21 in the Basin Setting (Section 3) of the Santa Rosa Plain GSP for a map displaying the extent of the Santa Rosa Plain Subbasin which establishes the extent of the reported groundwater budget. A full summary of the groundwater inflow and outflow terms, their associated data sources that served as input to the model, and any limitations associated with each water budget term are presented in Table 3-3 in the Basin Setting section of the Santa Rosa Plain GSP. A list of the inflow and outflow terms associated with groundwater budget are provided as follows:

Groundwater inflows to Santa Rosa Plain Subbasin include:

- Deep percolation from precipitation and applied irrigation water
- Septic return flows
- Streambed recharge to groundwater
- Subsurface inflows, including:
    - Inflow from Wilson Grove Formation Highlands Subbasin (Wilson Grove Subbasin and Wilson Grove Subbasin Boundary Condition)
    - Inflow from Healdsburg Area Subbasin (Healdsburg Area Subbasin Boundary Condition)
    - Inflow from Petaluma Valley Basin (Petaluma Valley Subbasin Boundary Condition)
    - Inflow from Rincon-Kenwood Subbasin
- Subsurface inflow from the surrounding watershed that are not other DWR subbasins, or mountain-front recharge (including the "island" just west of Cotati)

Groundwater outflows from Santa Rosa Plain Subbasin include:

- Crop, native vegetation and riparian evapotranspiration (ET)
- Groundwater pumping (including municipal and industrial, rural domestic, and agricultural)
- Groundwater discharge to streams
- Subsurface outflows:
    - Outflow to Wilson Grove Formation Highlands Subbasin (Wilson Grove Subbasin and Wilson Grove Subbasin Boundary Condition)
    - Outflow to Healdsburg Area Subbasin (Healdsburg Area Subbasin Boundary Condition)
    - Outflow to Petaluma Valley Subbasin (Petaluma Valley Basin Boundary Condition)
    - Outflow to Rincon-Kenwood Subbasin
- Surface leakage, which is groundwater discharge to soil zone (rejected recharge to the surface in shallow groundwater areas)

All groundwater inflows and outflows are simulated and summarized based on the historical simulations of SRPHM. The results section of this TM will provide a high-level quantitative summary of these groundwater water inflow and outflow terms.

3.4.3 Petaluma Valley Subbasin

As part of GSP development, a groundwater budget was developed to characterize the groundwater inflows and outflows to the Petaluma Valley Subbasin. Refer to Figure 3-22 in the Basin Setting (Section 3) of the Petaluma Valley Subbasin GSP for a map displaying the extent of the Petaluma Valley Subbasin which establishes the extent of the reported groundwater budget. A full summary of the groundwater inflow and outflow terms, their associated data sources that served as input to the model, and any limitations associated with each water budget term are presented in Table 3-3 in the Basin Setting section of the Petaluma Valley Subbasin GSP. A list of the inflow and outflow terms associated with groundwater budget are provided as follows:

Groundwater inflows to Petaluma Valley Subbasin include:

- Septic return flows
- Subsurface Boundary Inflows:
- Boundary flow from Santa Rosa Plain
- Boundary flow from Baylands
- Boundary flow from the Petaluma River

- Groundwater Inflow from Wilson Grove Formation Highlands Basin
- Areal recharge (includes deep percolation from both precipitation and applied irrigation water)
- Stream leakage to groundwater

Groundwater outflows from Petaluma Valley include:

- Groundwater pumpage (including municipal, rural domestic, and agricultural)
- Subsurface Boundary Outflows:
- Boundary flow to Santa Rosa Plain
- Boundary flow to the Petaluma River
- Boundary flow to the Baylands
- Groundwater outflow to Wilson Grove Formation Highlands Basin
- Surface Leakage – Rejected recharge occurring where phreatic water levels exceed ground surface elevation
- Groundwater ET from crops, native vegetation, and riparian vegetation
- Groundwater discharge to streams

All groundwater inflows and outflows are simulated and summarized based on the historical simulations of PVIHM. The results section of this TM will provide a high-level quantitative summary of these groundwater water inflow and outflow terms.

3.4.4 Sonoma Valley Subbasin

As part of GSP development, a groundwater budget was developed to characterize the groundwater inflows and outflows to the Sonoma Valley groundwater basin. Refer to Figure 3-25 in the Basin Setting (Section 3) of the Sonoma Valley GSP for a map displaying the extent of the Sonoma Valley groundwater subbasin which establishes the extent of the reported groundwater budget. A full summary of the groundwater inflow and outflow terms, their associated data sources that served as input to the model, and any limitations associated with each water budget term are presented in Table 3-2 in the Basin Setting section of the Sonoma Valley GSP. A list of the inflow and outflow terms associated with groundwater budget are provided as follows:

Groundwater inflows to Sonoma Valley include:

- Areal recharge (includes deep percolation from both precipitation and applied irrigation water)
- Septic return flows
- Streambed recharge to groundwater
- Subsurface inflows:
  - Inflow from Kenwood Valley Subbasin
  - Inflow from Baylands
  - Inflow from Margins
- Mountain-front recharge – Subsurface inflow from the surrounding watershed

Groundwater outflows from Sonoma Valley include:

- Groundwater ET from crops, native vegetation, and riparian vegetation with roots below groundwater table
- Groundwater pumpage (including municipal, rural domestic, and agricultural)
- Groundwater discharge to streams
- Subsurface outflows:
  - Outflow to Kenwood Valley Subbasin

    - Outflow to Baylands
    - Outflow to Margins
- Surface leakage (represents rejected recharge occurring where phreatic water levels exceed ground surface elevation)

All groundwater inflows and outflows are simulated and summarized based on the historical simulations of SVIGFM v2. The results section of this TM will provide a high-level quantitative summary of these groundwater water inflow and outflow terms.

3.5 Total Water Budget

The following sections describe the structure of the total water budget system used to develop total water budgets for the Russian River WBAs. Total water budgets were not included in the Santa Rosa Plain, Petaluma Valley, and Sonoma Valley subbasin GSPs, thus, total water budgets are not presented for these subbasins in this TM.

3.5.1 Russian River Watershed

The Russian River Watershed GSFLOW Model simulates the total system water fluxes using a combination of PRMS, MODFLOW, and the Ag Package. Total water budgets for the Russian River watershed are estimated using the following Russian River Watershed GSFLOW Model outputs given in **Table 5**. 'Streamflow In' includes flows into the Russian River watershed from the Potter Valley Project (PVP) and Mark West Creek. Contributions from these inflows are reflected in 'Streamflow In' values in the Russian River Surface Water Budget (PVP and Mark West Creek), the Upper Russian River Subbasin (PVP), and the Lower Russian River Subbasin (Mark West Creek).

Table 5: Total water budget components, with the descriptive water budget component name, the model output term (and whether the term is from MODFLOW, PRMS, or the Ag package), and whether the component describes an inflow, outflow, or a net flux

Descriptive name	Russian River Watershed GSFLOW Model output	Inflow, outflow, or net flux
net groundwater boundary flux	*From Other Zones IN + From Other Zones OUT + HEAD DEP BOUNDS IN + HEAD DEP BOUNDS OUT* (MODFLOW)	Net flux
rural domestic groundwater pumping	*WELLS OUT* (MODFLOW)	Outflow
municipal and industrial groundwater pumping	*MNW2 OUT* (MODFLOW)	Outflow
total evapotranspiration	*hru_actet + GW ET OUT* (PRMS + MODFLOW)	Outflow

Total precipitation	*hru_ppt* (PRMS)	Inflow
net head dependent boundary flux	*HEAD DEP BOUNDS IN* + *HEAD DEP BOUNDS OUT* (MODFLOW)	Net flux
net constant head flux	*CONSTANT HEAD IN* + *CONSTANT HEAD OUT* (MODFLOW)	Net flux
Streamflow in	*gage files* (MODFLOW)	Inflow
Streamflow out	*gage files* (MODFLOW)	Outflow
storage*	*STORAGE IN* + *STORAGE OUT* (MODFLOW)	Net flux

* NOTE: Positive storage values indicate the volume of water that is released from groundwater storage. Negative storage values indicate the volume of water that is partitioned into groundwater storage

3.6 Limitations

The Russian River Watershed GSFLOW Model offers a platform for comprehensive accounting of water inputs, outputs and fluxes within the Russian River watershed. Additionally, the models associated with GSP development provide a representation of water accounting for their respective groundwater subbasins and surrounding watershed areas. All hydrologic models, including sophisticated models like these, can have significant uncertainties associated with the individual budget terms due to a combination of limitations, including limitations in physical process representation, spatial and temporal aggregation, as well as availability and accuracy of data used to develop the modeling tool.

For the Russian River Watershed GSFLOW Model, detailed accounting of the modeling tool, including comparison of some simulated water budget terms against measurements (e.g., streamflow) is presented in the forthcoming publication from USGS (Adera et al., *in review*), which will offer greater insight into these uncertainties.

Similar limitations as those described above for hydrologic models, each GSP identified limitations of the modeling tools used to support GSP development. Further details modeling assumption limitations in development of water budgets are described in Section 3.3.2 in the Santa Rosa Plain GSP, Section 3.3.2 in the Petaluma Valley GSP, and Section 3.4 in the Sonoma Valley GSP. A brief summary of model limitations are provided as follows:

- Estimates and spatial distribution of agricultural and rural domestic pumpage
- Amount and spatial distribution of precipitation
- Long-term stream discharge
- Vertical distribution of hydraulic head in deeper aquifer zones
- Aquifer hydraulic properties due to complexity of geology
- Rates of mountain-front recharge and its movement into the Subbasin

4. Results

4.1 Surface Water Annual Results

The following section presents and describes the surface water budget results on an annual basis for the Russian River Watershed and the Santa Rosa Plain, Petaluma Valley, and Sonoma Valley subbasins.

4.1.1 Russian River Watershed

Table 6 provides a summary of the historical Russian River Watershed annual surface water budget for the four WBAs that make up the Russian River Watershed. **Attachment A** includes bar charts of the annual surface water budgets to give a sense of annual variability in the water budget terms summarized in **Table 6**. Aside from the streamflow in and streamflow out terms, which tracks total streamflow coming in and out of these WBAs, the largest surface water budget term across all four WBAs is the runoff and subsurface interflow to streams term. The net groundwater flux to and from streams is negative for the Upper Russian River, Alexander Valley, and Lower River WBAs suggesting that the streams in this area are generally losing surface water to groundwater on an annual average basis. Relatively large negative net groundwater fluxes from streams and lakes in the Lower River WBA reflects, in part, Russian River diversions via riverbank filtration by Sonoma Water, as well as model representation of water fluxes exiting the model at the Russian River mouth (Subbasin 22). Agricultural diversions occur within all four WBAs, with the largest volume of agricultural diversions occurring in the Upper Russian River.

Table 6. Historical (WYs 1991 through 2015) Russian River Watershed Annual Average Surface Water Budget Summary

Water Budget Term	Upper Russian River (AF)	Alexander Valley (AF)	Dry Creek (AF)	Lower River (AF)
Net groundwater flux to/from lakes	-600	0	-1,000	-30,200
Net groundwater flux to/from streams	-4,200	-3,600	300	-72,100
Runoff and subsurface interflow to streams	492,300	271,900	249,800	321,700
Runoff and subsurface interflow to lakes	1,900	0	21,300	0
Total agricultural diversions	-12,500	-4,000	-1,500	-2,100
Streamflow in	1,404,800	3,052,600	584,200	5,351,500
Streamflow out	-1,880,300	-3,319,700	-849,000	-5,584,500

Note:

Positive values represent an inflow to the surface water system

Negative values represent an outflow from the surface water system

4.1.2 Santa Rosa Plain Subbasin

Full presentation and discussion of the Santa Rosa Plain Subbasin surface water budget is presented in Section 3.3.3.1 of Section 3 of the Santa Rosa Plain GSP. The following section provides a high-level overview of the annual historical surface water budget.

Table 7 provides a summary of the historical average surface water budget for the Santa Rosa Plain. Net streambed exchange reflects the net stream-aquifer interaction (groundwater discharge to streams minus streambed recharge to groundwater). On average, groundwater discharge to streams exceeds streambed recharge to groundwater, resulting in a positive value of approximately 300 acre-feet per year (AFY), and is the smallest term in the surface water budget. The GSP determined that the streambed exchange depends less on year-to-year variability in precipitation, and more on 5- to 10-year climatic variability in precipitation as gaining and losing conditions change along streams depending on groundwater conditions. Net streambed exchange ranged from approximately -4,400 AFY to 5,200 AFY. While net streambed exchange is generally positive, net losing conditions can occur in years following consecutive dry years. For example, WY 2017 (wet year) experienced net losing conditions due to WYs 2012 to 2016 all being dry or normal years.

Boundary inflows and boundary outflows reflect the largest water budget terms in the Santa Rosa Plain surface water budget (**Table 7**). On average, the boundary outflows tend to be larger than the boundary inflows which occurred primarily due to the generation of overland runoff within the Santa Rosa Plain subbasin. The largest net streamflows entering the Santa Rosa Plain subbasin (boundary inflows) are from Upper Santa Rosa Creek and Upper Laguna de Santa Rosa. Boundary inflows ranged from approximately 32,200 to 868,600 AFY over the historical period. The largest net streamflows exiting the Santa Rosa Plain subbasin (boundary outflows) are from Porter Creek-Mark West Creek and Windsor Creek. Boundary outflows ranged from approximately -1,161,600 to -46,600 AFY over the historical period.

Table 7. Historical (WY 1976 to WY 2018) Surface Water Budget Summary for the Santa Rosa Plain Subbasin

Water Budget Term	Santa Rosa Plain Subbasin (AF)
Net streambed exchange	300
Overland runoff to streams	130,00
Boundary outflows	-492,200
Boundary inflows	362,000

4.1.3 Petaluma Valley Subbasin

Full presentation and discussion of the Petaluma Valley Subbasin surface water budget is presented in Section 3.3.3.1 of Section 3 of the Petaluma Valley GSP. The following section provides a high-level overview of the annual historical surface water budget.

Table 8 provides a summary of the historical average surface water inflows budget for the Petaluma Valley Subbasin. The largest surface water inflow term is the groundwater discharge streams (98,900 AFY), followed by surface water boundary inflow (69,300 AFY), and runoff (65,100 AFY).

Table 8. Historical (WY 1969 through WY 2018) Surface Water Inflows Budget Summary for the Petaluma Valley Subbasin

Water Budget Term	Petaluma Valley Subbasin (AF)
Surface water boundary inflow	69,300
Runoff	65,100
Groundwater discharge to streams	98,800
Total inflows	233,200

Table 9 provides a summary of the historical average surface water outflows budget for the Petaluma Valley Subbasin. The largest surface water outflow term is the surface water boundary outflow (-150,700 AFY), followed by stream leakage to groundwater (-97,200 AFY). Surface water diversions comprise a relatively small portion of the surface water outflows and overall surface water budget at -700 AFY on average during the historical period.

Net stream leakage, which is calculated as the difference between groundwater discharge to streams and stream leakage to groundwater ranges from -12,000 AFY up to 14,000 AFY. On average, the net stream leakage is approximately 1,600 AFY which suggests that the streams in the Petaluma Valley Subbasin have generally gained water over the historical period. However, net stream leakage varies with climatic variations and corresponding groundwater conditions that define the degree of interconnection between streams and the underlying water table.

Table 9. Historical (WY 1969 through WY 2018) Surface Water Outflows Budget Summary for the Petaluma Valley Subbasin

Water Budget Term	Petaluma Valley Subbasin (AF)
Surface water boundary outflow	150,700
Diversions	700
Stream leakage to groundwater	97,200
Total outflows	248,600

4.1.4 Sonoma Valley Subbasin

Full presentation and discussion of the Sonoma Valley Subbasin surface water budget is presented in Section 3.4.1.1 of Section 3 of the Sonoma Valley GSP. The following section provides a high-level overview of the annual historical surface water budget.

Table 10 provides a summary of the historical average surface water inflows budget for the Sonoma Valley Subbasin. The largest surface water inflow term is the surface water inflow from streams (43,000 AFY), followed by overland flow (32,200 AFY), mountain-front runoff (16,500 AFY), and groundwater discharge to streams (1,700 AFY).

Table 10. Historical (WY 1971 to WY 2018) Surface Water Inflows Budget Summary for the Sonoma Valley Subbasin

Water Budget Term	Sonoma Valley Subbasin (AF)
Surface water inflow from streams	43,000
Overland flow	32,200
Groundwater discharge to streams	1,700
Mountain-front runoff	16,500
Total inflows	93,400

Table 11 provides a summary of the historical average surface water outflows budget for the Sonoma Valley Subbasin. The largest surface water outflow term is the surface water outflows term (92,500 AFY), followed by seepage to groundwater (800 AFY), and surface water diversions (100 AFY).

Table 11. Historical (WY 1971 to WY 2018) Surface Water Outflows Budget Summary for the Sonoma Valley Subbasin

Water Budget Term	Sonoma Valley Subbasin (AF)
Surface water outflows	92,500
Surface water diversions	100
Seepage to groundwater	800
Total outflows	93,400

Net stream leakage is calculated as the difference between groundwater inflows to streams and seepage to groundwater. For the Sonoma Valley Subbasin, historical average net stream leakage was approximately 900 AFY. However, net stream leakage varies with climatic conditions and ranges from nearly 0 acre-feet (AF) in very dry years up to 2,000 AF in very wet years.

4.2 Land System Annual Results

The following section presents and describes the land system water budget results on an annual basis for the Russian River Watershed and the Santa Rosa Plain, Petaluma Valley, and Sonoma Valley subbasins.

4.2.1 Russian River Watershed

Table 12 provides a summary of the historical Russian River Watershed annual land system water budget for the four WBAs that make up the Russian River Watershed. **Attachment B** includes bar charts of the annual land system water budgets for each of the four WBAs to give a sense of annual variability in the water budget terms summarized in **Table 12**. The largest land system water budget term across all four WBAs is the total precipitation term. The next largest terms are evapotranspiration and subsurface flow (interflow) to stream network. The largest volume of agricultural groundwater pumping occurs in the Alexander Valley, followed by the Upper Russian River, and Lower River. The largest agricultural diversion occurs in the Upper Russian River, followed by the Alexander Valley and Lower River.

Table 12. Historical (WYs 1991 through 2015) Russian River Watershed Annual Average Land System Water Budget Summary

Water Budget Term	Upper Russian River (AF)	Alexander Valley (AF)	Dry Creek (AF)	Lower River (AF)
Agricultural groundwater pumping	2,000	5,900	900	1,400
Surface runoff to stream network	-47,600	-27,800	-9,300	-40,300
Total precipitation	1,060,500	609,700	538,000	598,000
Evapotranspiration (excluding ET from groundwater)	-549,500	-310,000	-257,500	-258,500
Subsurface flow (interflow) to stream network	-444,700	-244,200	-240,500	-281,300
Total agricultural diversions	12,500	4,000	1,500	2,100
recharge	-94,900	-100,600	-31,900	-51,900

Note:

Positive values represent an inflow to the landscape system

Negative values represent an outflow from the landscape system

4.2.2 Santa Rosa Plain Subbasin

Full presentation and discussion of the Santa Rosa Plain Subbasin land system water budget is presented in Section 3.3.3.3 of Section 3 of the Santa Rosa Plain Subbasin GSP. The following section provides a high-level overview of the annual historical land system budget.

Table 13 presents a summary of the historical land system inflows to the Santa Rosa Plain subbasin. On average, the largest inflow term is precipitation (248,800 AFY), followed by agricultural irrigation water added to the soil zone (10,600 AFY).

Table 13. Historical (WY 1976 to WY 2018) Land System Budget Inflows Summary to the Santa Rosa Plain Subbasin

Water Budget Term	Santa Rosa Plain Subbasin (AF)
Precipitation	248,800
Agricultural irrigation water added to the soil zone	10,600
Total inflows	259,400

Table 14 presents a summary of the historical land system outflows from the Santa Rosa Plain subbasin. On average, the three largest outflow terms are ET in the soil zone (107,300 AFY), followed by rejected soil water that flows to the stream network (62,200 AFY), and soil-zone recharge (53,000 AFY).

Table 14. Historical (WY 1976 to WY 2018) Land System Budget Outflows Summary from the Santa Rosa Plain Subbasin

Water Budget Term	Santa Rosa Plain Subbasin (AF)
ET in the soil zone	107,300
Soil-zone recharge	53,000
Rejected soil water that flows to the stream network (Dunnian flow)	62,200
Lateral flow of soil water to the stream network (Interflow)	7,400
Total outflows	229,900

4.2.3 Petaluma Valley Subbasin

Full presentation and discussion of the Petaluma Valley Subbasin land system water budget is presented in Section 3.3.3.2 of Section 3 of the Petaluma Valley Subbasin GSP. The following section provides a high-level overview of the annual historical land system budget.

Table 15 presents a summary of the historical land system inflows to the Petaluma Valley subbasin. On average, the largest inflow term is precipitation (109,600 AFY), followed by agricultural pumpage (5,100 AFY).

Table 15. Historical (WY 1969 through WY 2018) Land System Budget Inflows Summary for the Petaluma Valley Subbasin

Water Budget Term	Petaluma Valley Subbasin (AF)
Precipitation	109,600
Surface water diversions and recycled water	900
Agricultural pumpage	5,100
Total inflows	115,600

Table 16 presents a summary of the historical land system outflows from the Petaluma Valley subbasin. On average, the three largest outflow terms are runoff (68,200 AFY), followed by ET of precipitation (34,900 AFY), and ET of groundwater (22,100 AFY).

Table 16. Historical (WY 1969 through WY 2018) Land System Budget Outflows Summary for the Petaluma Valley Subbasin

Water Budget Term	Petaluma Valley Subbasin (AF)
ET of precipitation	34,900
ET of groundwater	22,100
ET of irrigation	3,600
Runoff	68,200
Deep percolation	20,700
Total outflows	149,500

4.3 Groundwater Annual Results

The following section presents and describes the groundwater system water budget results on an annual basis for the Russian River Watershed and the Santa Rosa Plain, Petaluma Valley, and Sonoma Valley subbasins.

4.3.1 Russian River Watershed

Table 17 provides a summary of the historical Russian River Watershed annual groundwater budget for the four WBAs that make up the Russian River Watershed. **Attachment C** includes bar charts of the annual groundwater budgets to give a sense of annual variability in the water budget terms summarized in **Table 17**. Recharge and evapotranspiration from groundwater are generally the two largest terms in the groundwater budget across all four WBAs. The largest amount of municipal and industrial groundwater pumping occurs in the Lower River, largely reflecting Sonoma Water's Russian River diversions via riverbank filtration. The Upper Russian River and Dry Creek WBAs all show small, negative changes in groundwater storage, suggesting that the groundwater system may be experiencing small declines in groundwater storage over the historical period. The Lower River, however, on average, shows a positive change in groundwater storage, suggesting the groundwater storage may be increasing over the historical period.

Table 17. Historical (WYs 1991 through 2015) Russian River Watershed Annual Average Groundwater Budget Summary

Water Budget Term	Upper Russian River (AF)	Alexander Valley (AF)	Dry Creek (AF)	Lower River (AF)
Agricultural groundwater pumping	-2,000	-5,900	-900	-1,400
Evapotranspiration from groundwater	-24,000	-30,200	-8,300	-6,600
Net groundwater boundary flux	-100	0	-200	-52,700
Net groundwater flux to/from lakes	600	0	1,100	30,200
Municipal and industrial	-5,500	-4,200	-800	-70,100

groundwater pumping				
Net groundwater flux to/from land surface	-1,800	-2,300	-1,100	-4,600
Net groundwater flux to/from stream network	4,200	3,600	-300	72,100
Recharge	33,600	38,700	11,500	23,500
Rural domestic groundwater pumping	-5,300	-870	-700	-1,300
Storage*	-500	0	-500	1,000

Note:

Positive values represent an inflow to the groundwater system

Negative values represent an outflow from the groundwater system

*Positive storage values indicate the volume of water that is released from storage. Negative storage values indicate the volume of water that is partitioned into storage.

4.3.2 Santa Rosa Plain Subbasin

Full presentation and discussion of the Santa Rosa Plain groundwater water budget is presented in Section 3.3.3.2 of Section 3 of the Santa Rosa Plain GSP. The following section provides a high-level overview of the annual historical groundwater budget.

Table 18 presents a summary of the historical groundwater inflows to the Santa Rosa Plain subbasin. On average, the largest inflow term is the deep percolation of precipitation and applied water (28,700 AFY), followed by streambed recharge to groundwater (15,100 AFY), and subsurface inflow from neighboring basins (7,400 AFY).

Table 18. Historical (WY 1976 to WY 2018) Groundwater Inflows Budget Summary for the Santa Rosa Plain Subbasin

Water Budget Term	Santa Rosa Plain Subbasin (AF)
Deep percolation of precipitation and applied water	28,700
Streambed recharge to groundwater	15,100
Septic return flows	1,000
Subsurface inflow from surrounding watershed	2,100
Subsurface inflow from neighboring basins	7,400
Total inflows	54,300

Table 19 presents a summary of the historical groundwater outflows from the Santa Rosa Plain subbasin. On average, the largest outflow term is discharge to streams (15,400 AFY), followed by M&I + rural domestic pumping (10,000 AFY), and groundwater ET (9,400 AFY). When combined, the agricultural and M&I + rural domestic groundwater pumping terms become the largest outflow from the groundwater system of the Santa Rosa Plain Subbasin.

Subsurface exchanges with the surrounding watershed and adjacent basins are generally a net inflow to the Santa Rosa Plain Subbasin, where subsurface inflows from adjacent basins tends to be larger than the subsurface outflow to adjacent basins. The largest subsurface inflows occurred from the Rincon-Kenwood and Wilson Grove Subbasins. The largest subsurface outflow term is the subsurface outflow to the Healdsburg Area Subbasin

Table 19. Historical (WY 1976 to WY 2018) Groundwater Outflows Budget Summary for the Santa Rosa Plain Subbasin

Water Budget Term	Santa Rosa Plain Subbasin (AF)
Agricultural pumping	9,100
Groundwater ET	9,400
Subsurface outflow to adjacent basins	4,900
Discharge to streams	15,400
Surface leakage	6,200
M&I and rural domestic pumping	10,000
Total outflows	55,000

4.3.3 Petaluma Valley Subbasin

Full presentation and discussion of the Petaluma Valley Subbasin groundwater water budget is presented in Section 3.3.3.3 of Section 3 of the Petaluma Valley GSP. The following section provides a high-level overview of the annual historical groundwater budget.

Table 20 provides a summary of the historical average groundwater inflows budget for the Petaluma Valley Subbasin. The three largest groundwater inflow terms are stream leakage to groundwater (97,200 AFY), followed by areal recharge (17,200 AFY), and groundwater inflow from Wilson Grove (15,700 AFY).

Table 20. Historical (WY 1969 through WY 2018) Groundwater Inflows Budget Summary for the Petaluma Valley Subbasin

Water Budget Term	Petaluma Valley Subbasin (AF)
Septic return flows	100
Boundary flow from Santa Rosa Plain	1,800
Boundary flow from the Baylands	5,400

Boundary flow from the Petaluma River	14,600
Groundwater inflow from Wilson Grove	15,700
Areal recharge	17,200
Stream leakage to groundwater	97,200
Total inflows	152,000

Table 21 provides a summary of the historical average groundwater outflows budget for the Petaluma Valley Subbasin. The three largest groundwater outflow terms are groundwater discharge to streams (98,800 AFY), followed by groundwater ET (18,800 AFY), and surface leakage (11,700 AFY).

Table 21. Historical (WY 1969 through WY 2018) Groundwater Inflows Budget Summary for the Petaluma Valley Subbasin

Water Budget Term	Petaluma Valley Subbasin (AF)
Boundary flow to the Baylands	0
Rural domestic pumpage	200
M&I pumpage	500
Boundary flow to Santa Rosa Plain	1,900
Agricultural pumpage	5,100
Groundwater outflow to Wilson Grove	5,800
Boundary flow to the Petaluma River	9,300
Surface leakage	11,700
Groundwater ET	18,800
Groundwater discharge to streams	98,800
Total outflows	152,100

4.3.4 Sonoma Valley Subbasin

Full presentation and discussion of the Sonoma Valley Subbasin groundwater budget is presented in Section 3.4.1.2 of Section 3 of the Sonoma Valley GSP. The following section provides a high-level overview of the annual historical surface water budget.

Table 21 provides a summary of the historical average groundwater inflows budget for the Sonoma Valley Subbasin. The three largest groundwater inflow terms are mountain-front recharge (5,100 AFY), followed by areal recharge (3,600 AFY), and subsurface flow in from Margins (3,200 AFY).

Table 21. Historical (WY 1971 to WY 2018) Groundwater Inflows Budget Summary for the Sonoma Valley Subbasin

Water Budget Term	Sonoma Valley Subbasin (AF)
Inflow from Baylands	600
Inflow from Kenwood Valley Subbasin	100
Inflow from Margins	3,200
Septic return flows	300
Streambed recharge to groundwater	800
Areal recharge	3,600
Mountain-front recharge	5,100
Total inflows	13,700

Table 22 provides a summary of the historical average groundwater outflows budget for the Sonoma Valley Subbasin. The three largest groundwater outflow terms are agricultural pumpage (3,400 AFY), followed by to surface leakage (2,700 AFY), and groundwater ET (2,300 AFY).

Table 22. Historical (WY 1971 to WY 2018) Groundwater Inflows Budget Summary for the Sonoma Valley Subbasin

Water Budget Term	Sonoma Valley Subbasin (AF)
Outflow to Baylands	800
Groundwater ET	2,300
Outflow to Kenwood Valley Subbasin	0
Agricultural pumpage	3,400
Outflow to Margins	1,300
Groundwater discharge to streams	1,700
Surface leakage	2,700
M&I and rural domestic pumpage	1,500
Total outflows	13,700

4.4 Total Water Budget Annual Results

The following section presents and describes the land system water budget results on an annual basis for the Russian River Watershed. Total water budgets were not developed as part of GSP development, thus, total water budgets for the Santa Rosa Plain, Petaluma Valley, and Sonoma Valley subbasins are not presented in this TM.

4.4.1 Russian River Watershed

Table 23 provides a summary of the historical Russian River Watershed total water budget for the four WBAs that make up the Russian River Watershed. **Attachment D** includes bar charts of the annual total water budgets to give a sense of annual variability in the water budget terms summarized in **Table 23**.

Table 23. Historical (WYs 1991 through 2015) Russian River Watershed Annual Average Total Water Budget Summary

Water Budget Term	Upper Russian River (AF)	Alexander Valley (AF)	Dry Creek (AF)	Lower River (AF)
Net groundwater boundary flux	-100	0	-200	-52,700
Net head dependent boundary flux	0	0	0	-52,900
Net constant head flux	0	0	0	0
Rural domestic groundwater pumping	-5,300	-900	-700	-1,300
Municipal and industrial groundwater pumping	-5,500	-4,200	-800	-70,100
Total evapotranspiration	-573,500	-340,100	-265,800	-265,100
Precipitation	1,060,500	609,700	538,000	598,000
Streamflow in	1,404,800	3,052,600	584,200	5,351,500
Streamflow out	-1,880,300	-3,319,700	-849,000	-5,584,500
Storage*	-500	0	-500	1,000

Note:

Positive values represent an inflow to the total water system

Negative values represent an outflow from the total water system

4.5 Monthly Results

The following section presents and describes monthly results for each water budget system for the Russian River Watershed and the Santa Rosa Plain subbasin. GSPs for the Petaluma Valley and Sonoma Valley subbasins did not include an analysis of monthly water budgets that could be summarized in this TM.

4.5.1 Russian River Watershed

Attachments A, B, C, and **D** also include bar charts of monthly average fluxes for each water budget term presented in the surface water, land system, groundwater, and total water budgets, respectively. These bar charts give a sense of the inter-annual variability of the inflows and outflows for each system. Observations associated with monthly variability of water budget terms for each system are summarized as follows:

Surface water system:

- Streamflow in and out predominantly occur during the winter months of December through March
- Surface water budget terms during the summer months and into the Fall (June through October) are notably smaller than the winter months, highlighting the large interannual variability in precipitation and surface water availability.

Land system:

- Total precipitation inflow occurs primarily from October through May with some precipitation in the month of June
    - Total precipitation is partitioned into surface runoff and subsurface flows to the stream network and groundwater recharge. During these months with the subsurface flow to stream network generally being the largest of these three terms
- Evapotranspiration occurs throughout the year but peaks from April through June

Groundwater system:

- Reductions in storage generally occur during the months of May through September, while increases in storage occur from October through April
- Recharge occurs year-round but peaks during the months of December through March
- Evapotranspiration from groundwater occurs primarily for the months of May through October

4.5.2 Santa Rosa Plain Subbasin

Figures 3-28 in Section 3 of the Santa Rosa Plain GSP presents monthly summaries of surface water budget terms to further characterize how hydrologic conditions vary throughout the year and across different water year types. In general, stream inflow and overland runoff are the main contributors to flows during the December to May period. Stream outflows tend to track stream inflows to the Santa Rosa Plain. Monthly values from WY 1999 (wet year) and WY 2016 (normal year) are compared due to distinctly different behavior across water budget terms in these two years. In WY 1999, net streambed recharge averages roughly zero during the months of December to March, whereas during WY 2016 net streambed recharge was mostly negative during these same months where streams recharged the Santa Rosa Plain Subbasin. In WY 1999, during the months of April through October, the net streambed recharge term is positive (streams gaining groundwater) while in WY 2016 only May and June are positive with the system reverting to losing conditions from July through October.

4.6 Changes in Groundwater Storage Results

The following section presents and describes the changes in groundwater storage for the Russian River Watershed WBAs and the Santa Rosa Plain, Petaluma Valley, and Sonoma Valley subbasins.

4.6.1 Russian River Watershed

Table 24 presents the historical annual average change in groundwater storage for the four Russian River WBAs. The change in groundwater storage on average is negative across the Upper Russian River, and Dry Creek WBAs, suggesting that the groundwater system is experiencing a decline in groundwater storage over the historical period. The Alexander Valley is not experiencing a net change in groundwater storage. The Lower River, however, on average, has a positive change in groundwater storage, suggesting the groundwater storage is generally increasing over the historical period.

Table 24. Historical (WYs 1991 through 2015) Russian River Watershed Annual Average Change in Groundwater Storage Summary

Water Budget Area	Historical Annual Average Change in Groundwater Storage (AF)
Upper Russian River	-500
Alexander Valley	0
Dry Creek	-500
Lower River	1,000

4.6.2 Santa Rosa Plain Subbasin

Refer to Figure 3-32 in Section 3 of the Santa Rosa Plain Subbasin GSP presents a full accounting of groundwater inflows and outflows and the annual and cumulative change in groundwater storage for the Santa Rosa Plain Subbasin. Historical average change in groundwater storage is -600 AFY suggesting a decline in groundwater storage over the historical period, on average. However, change in groundwater storage varies from year to year based on hydrologic conditions, thus the change in groundwater storage ranged from -22,000 to 20,000 AFY. Drier climate conditions in recent years resulted in an increased rate of groundwater storage depletion. With reference to Figure 3-33, which portrays annual groundwater pumping trends, the GSP concludes that the depletion of groundwater storage during recent years is not attributed to an increase in groundwater pumping. The decline in groundwater storage suggests that the Subbasin has not yet reached a dynamic equilibrium between inflows and outflows from the Santa Rosa Plain GSP.

4.6.3 Petaluma Valley Subbasin

Refer to Figure 3-31 in Section 3 of the Petaluma Valley Subbasin GSP presents a full accounting of groundwater inflows and outflows and the annual and cumulative change in groundwater storage for the Petaluma Valley Subbasin. Historical average change in groundwater storage is approximately -40 AFY but is rounded to a value of 0 AFY as presented in the GSP, suggesting a negligible change in groundwater storage over the historical period, on average. However, change in groundwater storage varies from year to year based on hydrologic conditions, thus the change in groundwater storage ranged from -18,300 to 19,500 AFY. The two largest declines in groundwater storage occurred during a drought from WY 1976 to WY 1978 with the largest increase in groundwater storage occurring in WY 1978 following the drought.

4.6.4 Sonoma Valley Subbasin

Figure 3-36 in Section 3 of the Sonoma Valley Subbasin GSP presents a full accounting of groundwater inflows and outflows and the annual and cumulative change in groundwater storage for the Sonoma

Valley Subbasin. Historical average change in groundwater storage is approximately -300 AFY, suggesting a decline in groundwater storage over the historical period, on average. However, change in groundwater storage varies from year to year based on hydrologic conditions, thus the change in groundwater storage ranged from -3,600 to 4,700 AFY. The two largest declines in groundwater storage occurred during a drought from WY 1976 to WY 1978 with the largest increase in groundwater storage occurring in WY 1978 following the drought. The total cumulative change in groundwater storage for WYs 1970 to 2018 is approximately -14,000 AF.

5. Discussion and Key Findings

Through development of historical water budgets for the four Russian River WBAs and through review of the Santa Rosa Plain, Petaluma Valley, and Sonoma Valley subbasin GSP water budgets, the following summarizes some key findings:

- Surface water budget terms during the summer months and into the Fall (June through October) are notably smaller than the winter months, highlighting the interannual variability in precipitation and surface water availability
- Evapotranspiration occurs throughout the year but peaks from April through June
- On average, three of the four Russian River WBAs and the Santa Rosa Plain, Petaluma Valley, and Sonoma Valley all show small declines in groundwater storage
- The cumulative decline in groundwater storage for the Sonoma Valley was approximately -14,000 AF for the historical period indicating serious declines in groundwater storage
- Increases in groundwater storage occur during wet years across all four Russian River WBAs and the Santa Rosa Plain, Petaluma Valley, and Sonoma Valley, suggesting that groundwater conditions are sensitive to annual variability in hydrologic conditions

6. References

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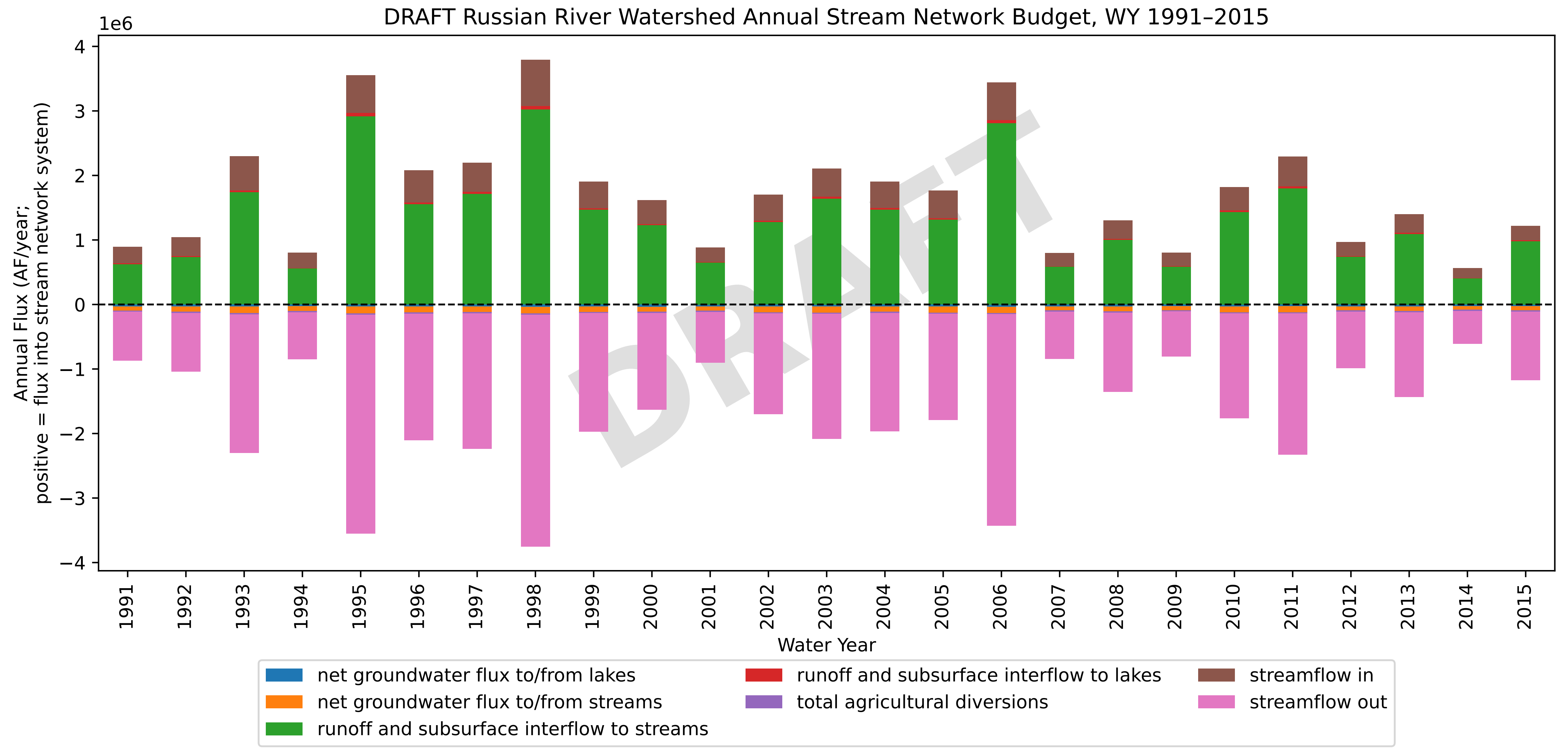
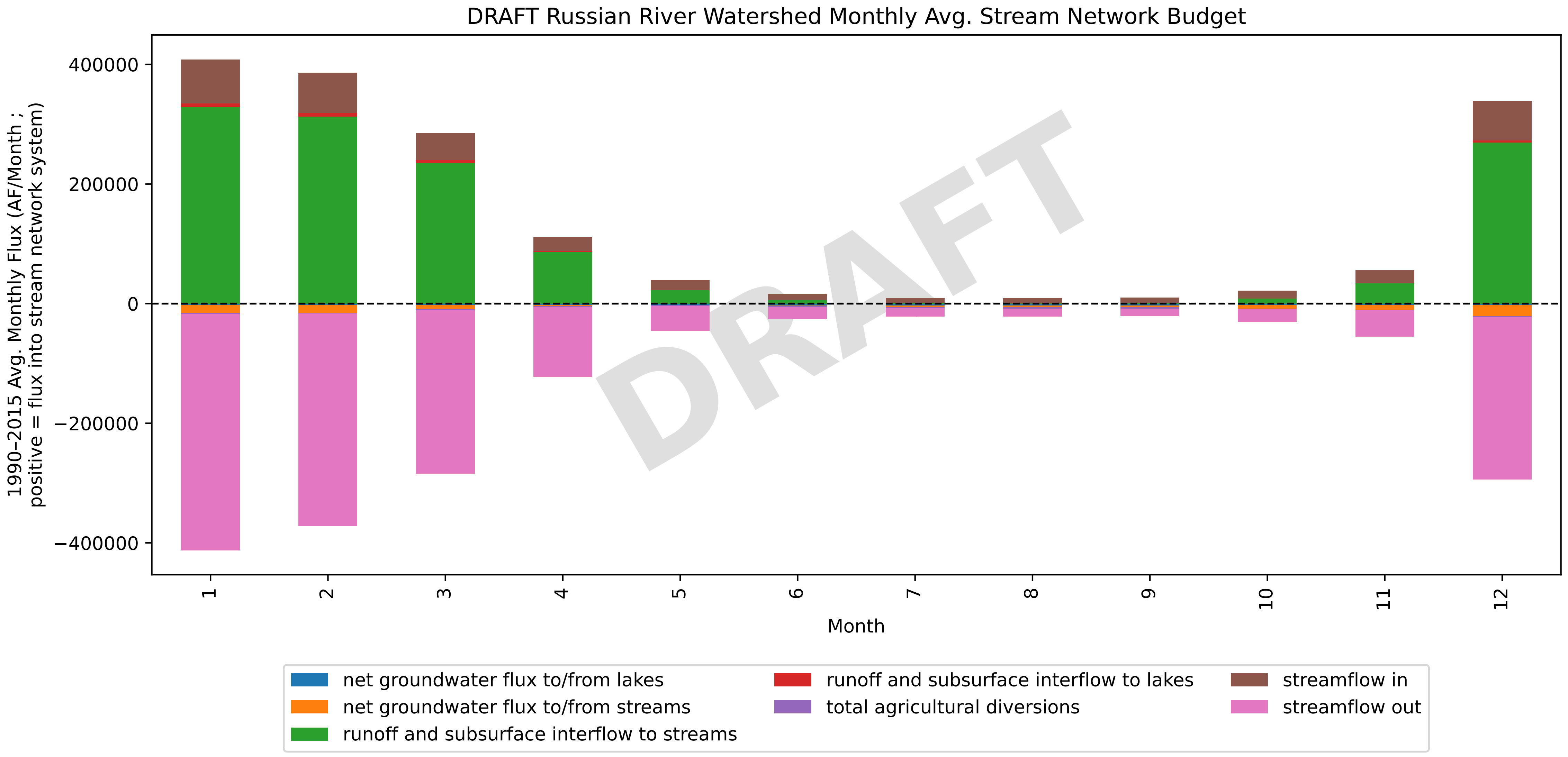
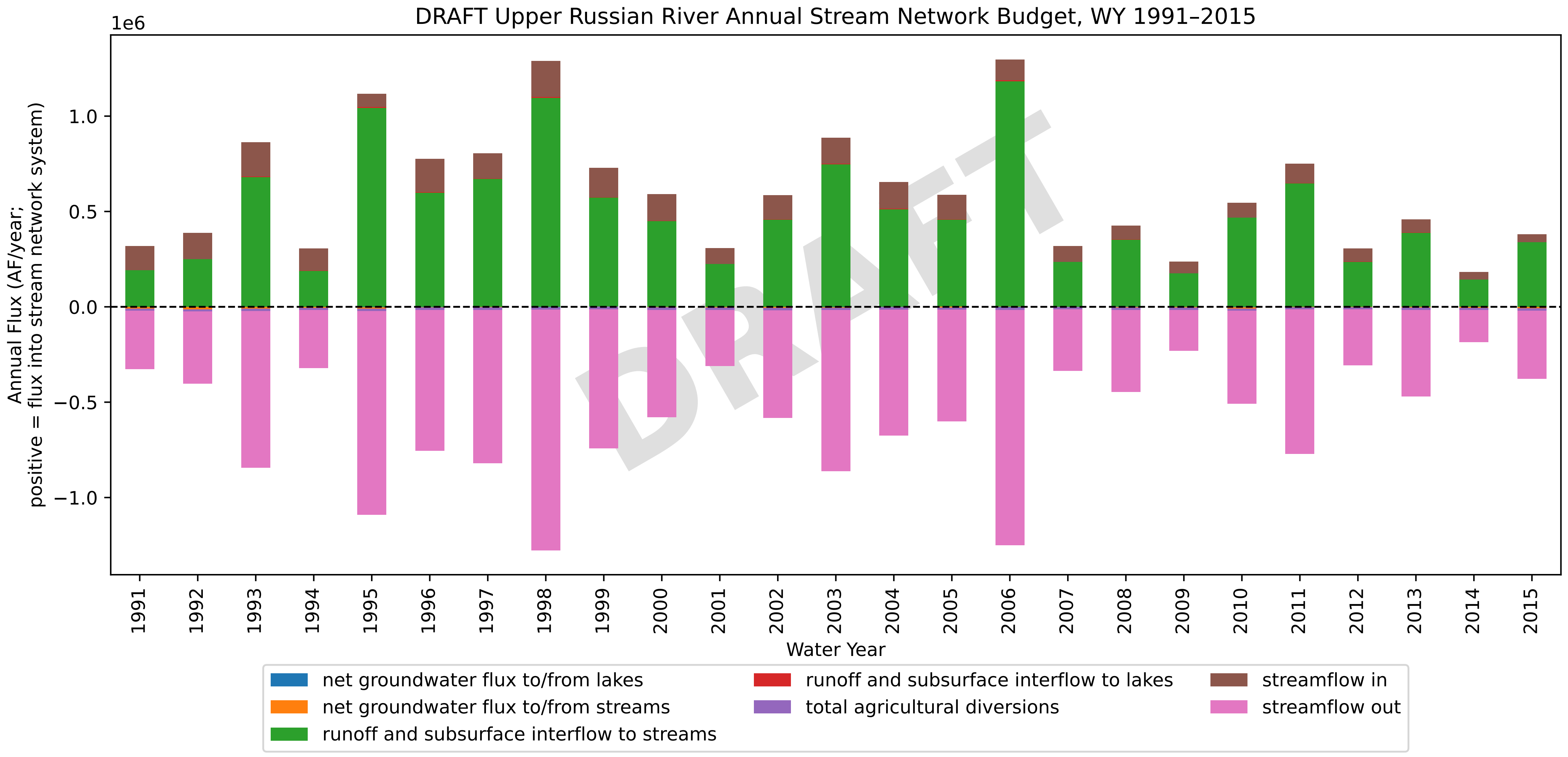
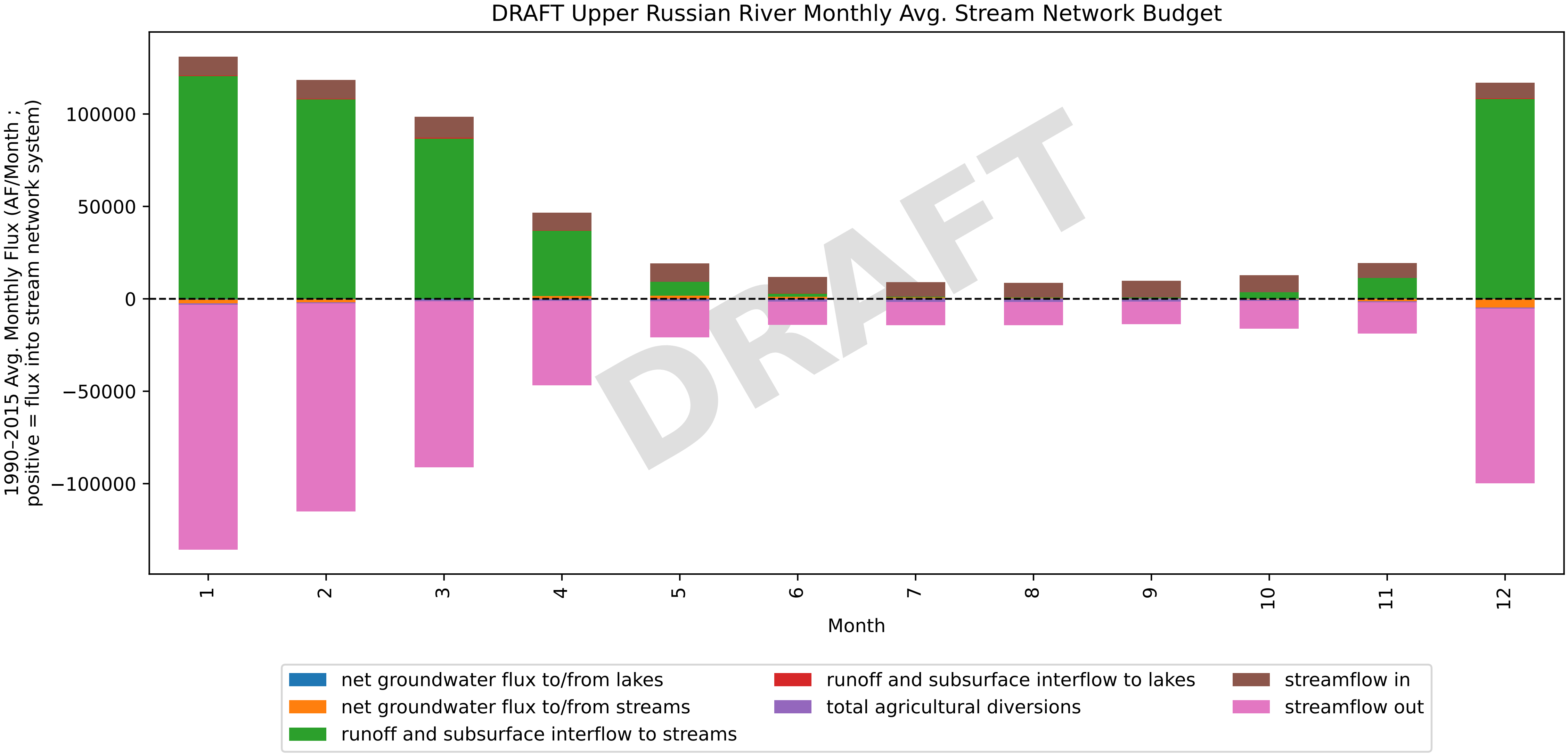
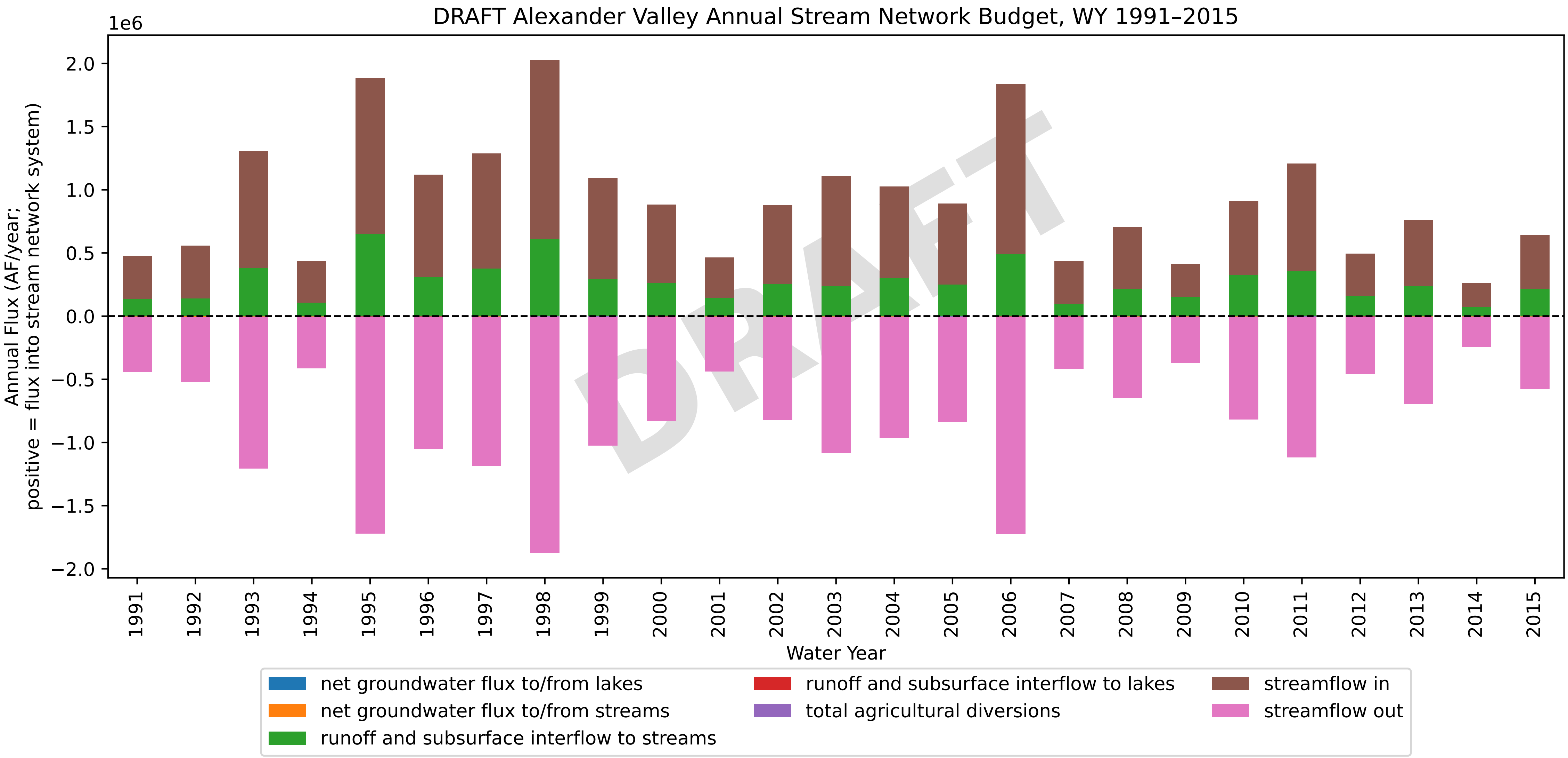
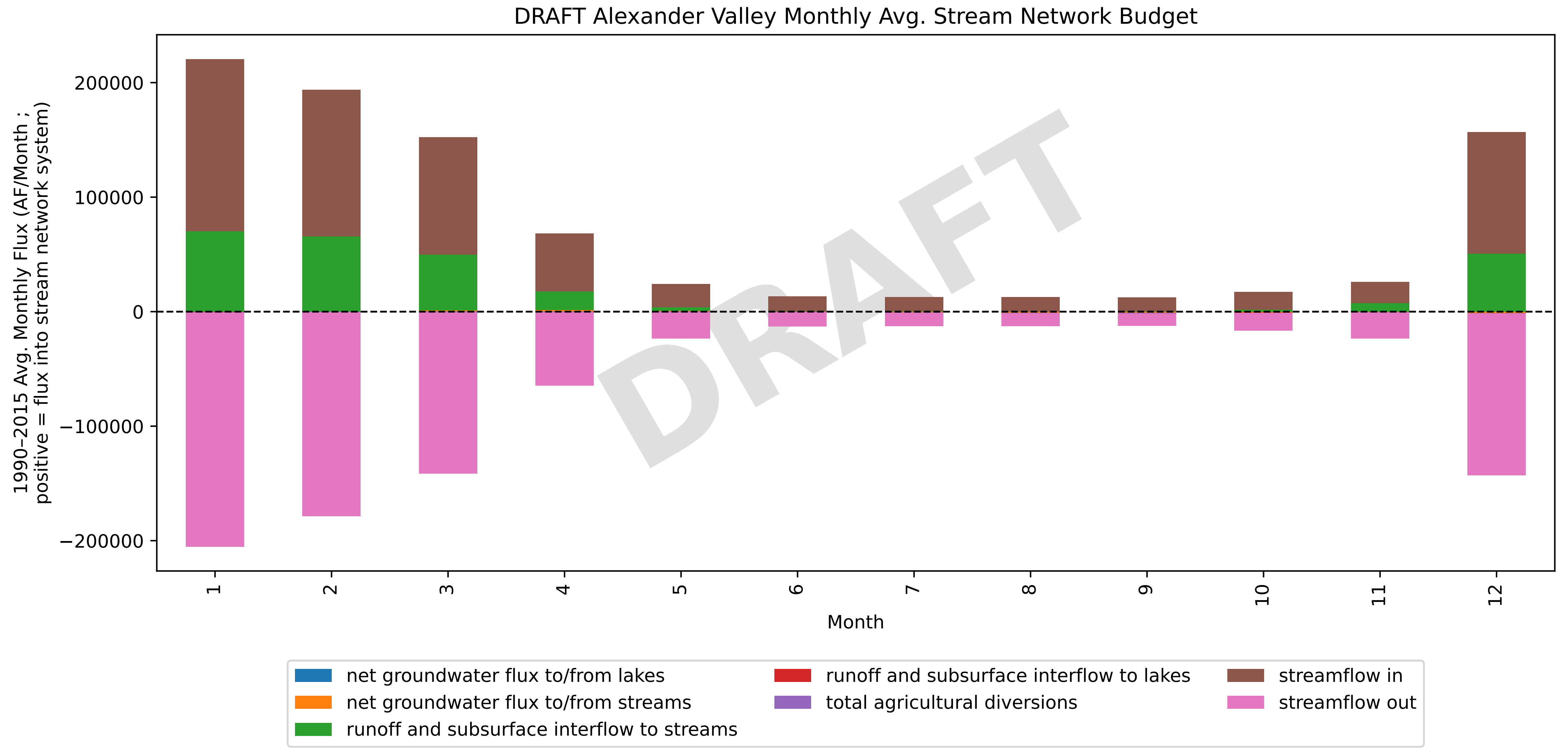

DRAFT Russian River Watershed Annual Stream Network Budget, WY 1991–2015
1e6
Annual Flux (AF/year;
positive = flux into stream network system)
4
3
2
1
0
−1
−2
−3
−4
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
Water Year
net groundwater flux to/from lakes
net groundwater flux to/from streams
runoff and subsurface interflow to streams
runoff and subsurface interflow to lakes
total agricultural diversions
streamflow in
streamflow out

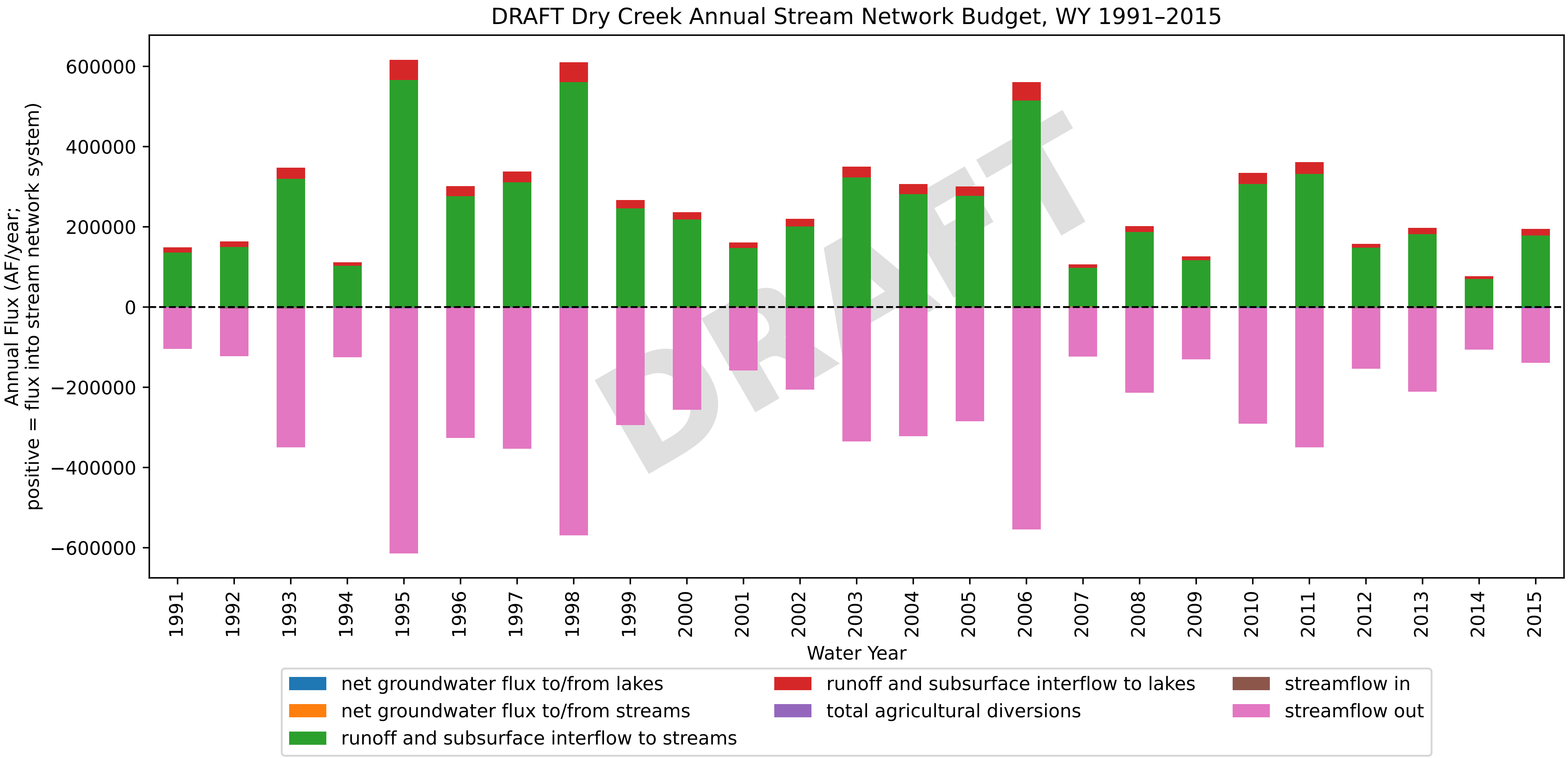

DRAFT Russian River Watershed Monthly Avg. Stream Network Budget
1990–2015 Avg. Monthly Flux (AF/Month ;
positive = flux into stream network system)
400000
200000
0
−200000
−400000
Month
1
2
3
4
5
6
7
8
9
10
11
12
DRAFT
net groundwater flux to/from lakes
net groundwater flux to/from streams
runoff and subsurface interflow to streams
runoff and subsurface interflow to lakes
total agricultural diversions
streamflow in
streamflow out


DRAFT Upper Russian River Annual Stream Network Budget, WY 1991–2015
1e6
1.0
0.5
0.0
−0.5
−1.0
Annual Flux (AF/year;
positive = flux into stream network system)
DRAFT
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
Water Year
net groundwater flux to/from lakes
net groundwater flux to/from streams
runoff and subsurface interflow to streams
runoff and subsurface interflow to lakes
total agricultural diversions
streamflow in
streamflow out


DRAFT Upper Russian River Monthly Avg. Stream Network Budget
1990–2015 Avg. Monthly Flux (AF/Month ;
positive = flux into stream network system)
100000
50000
0
−50000
−100000
1
2
3
4
5
6
7
8
9
10
11
12
Month
net groundwater flux to/from lakes
net groundwater flux to/from streams
runoff and subsurface interflow to streams
runoff and subsurface interflow to lakes
total agricultural diversions
streamflow in
streamflow out


DRAFT Alexander Valley Annual Stream Network Budget, WY 1991–2015
1e6
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
Annual Flux (AF/year;
positive = flux into stream network system)
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
Water Year
net groundwater flux to/from lakes
net groundwater flux to/from streams
runoff and subsurface interflow to streams
runoff and subsurface interflow to lakes
total agricultural diversions
streamflow in
streamflow out


DRAFT Alexander Valley Monthly Avg. Stream Network Budget
1990–2015 Avg. Monthly Flux (AF/Month ; positive = flux into stream network system)
200000
100000
0
−100000
−200000
1
2
3
4
5
6
7
8
9
10
11
12
Month
net groundwater flux to/from lakes
net groundwater flux to/from streams
runoff and subsurface interflow to streams
runoff and subsurface interflow to lakes
total agricultural diversions
streamflow in
streamflow out
DRAFT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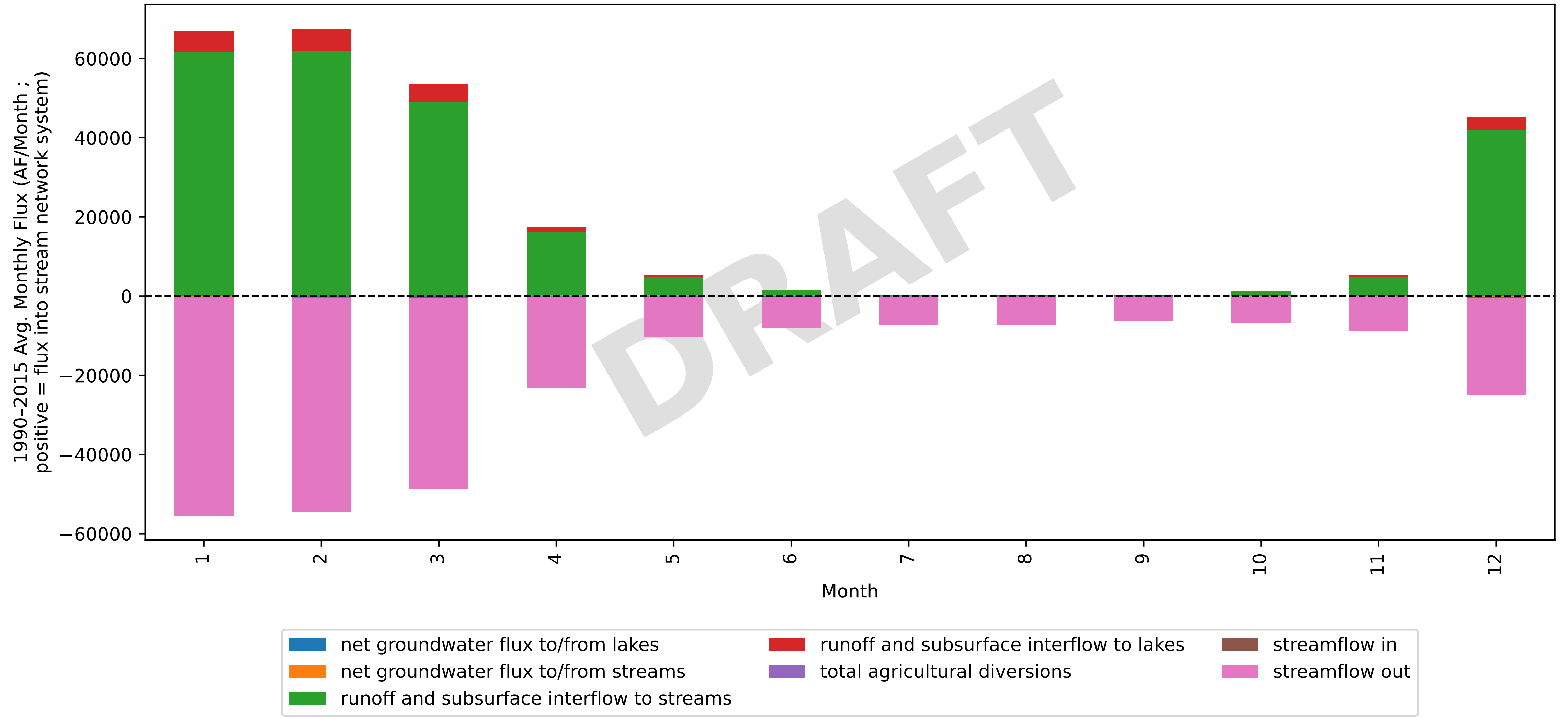
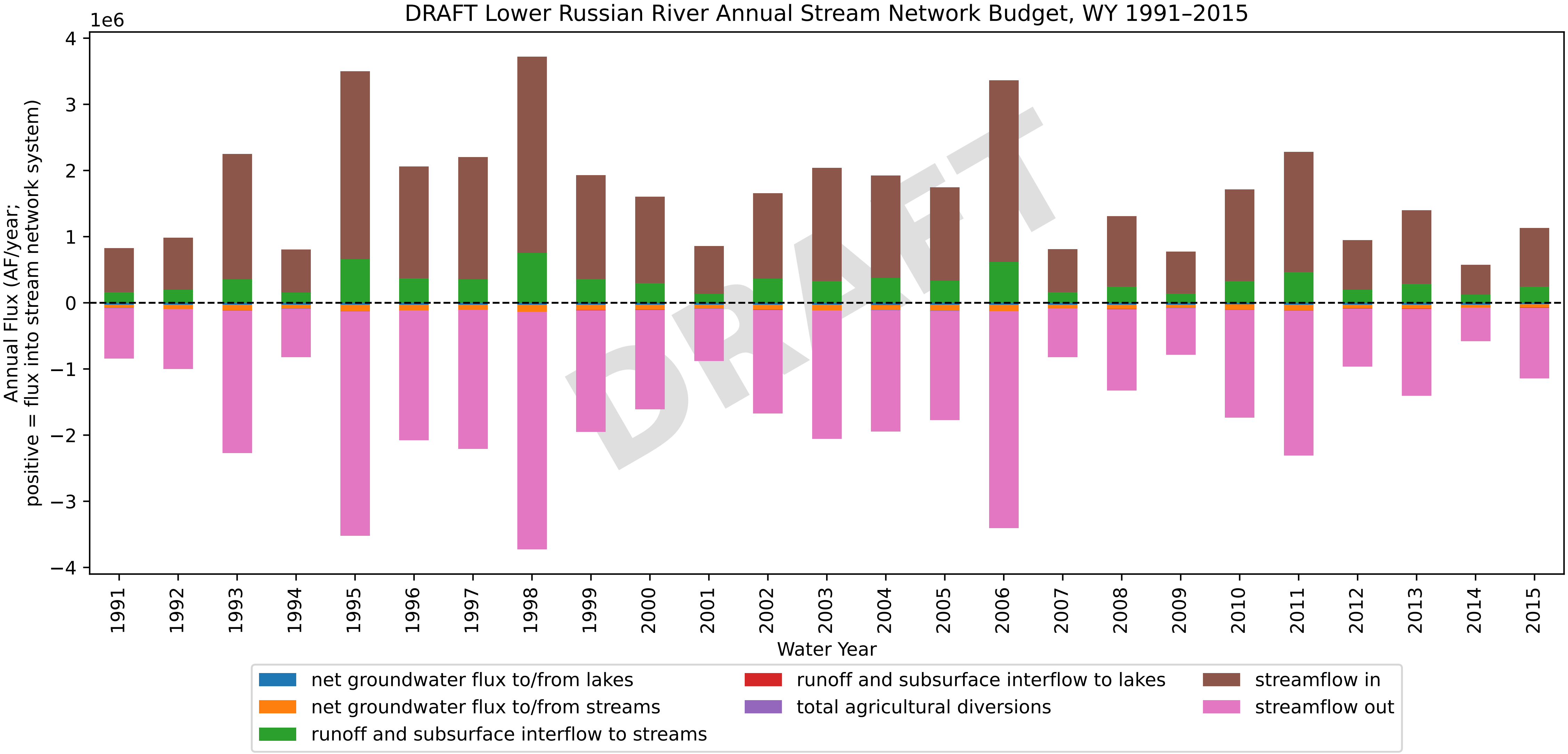
Annual Flux (AF/year;
positive = flux into stream network system)
600000
400000
200000
0
−200000
−400000
−600000
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
Water Year
net groundwater flux to/from lakes
net groundwater flux to/from streams
runoff and subsurface interflow to streams
runoff and subsurface interflow to lakes
total agricultural diversions
streamflow in
streamflow out



DRAFT Dry Creek Monthly Avg. Stream Network Budget


DRAFT Lower Russian River Annual Stream Network Budget, WY 1991–2015
1e6
4
3
2
1
0
−1
−2
−3
−4
Annual Flux (AF/year;
positive = flux into stream network system)
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
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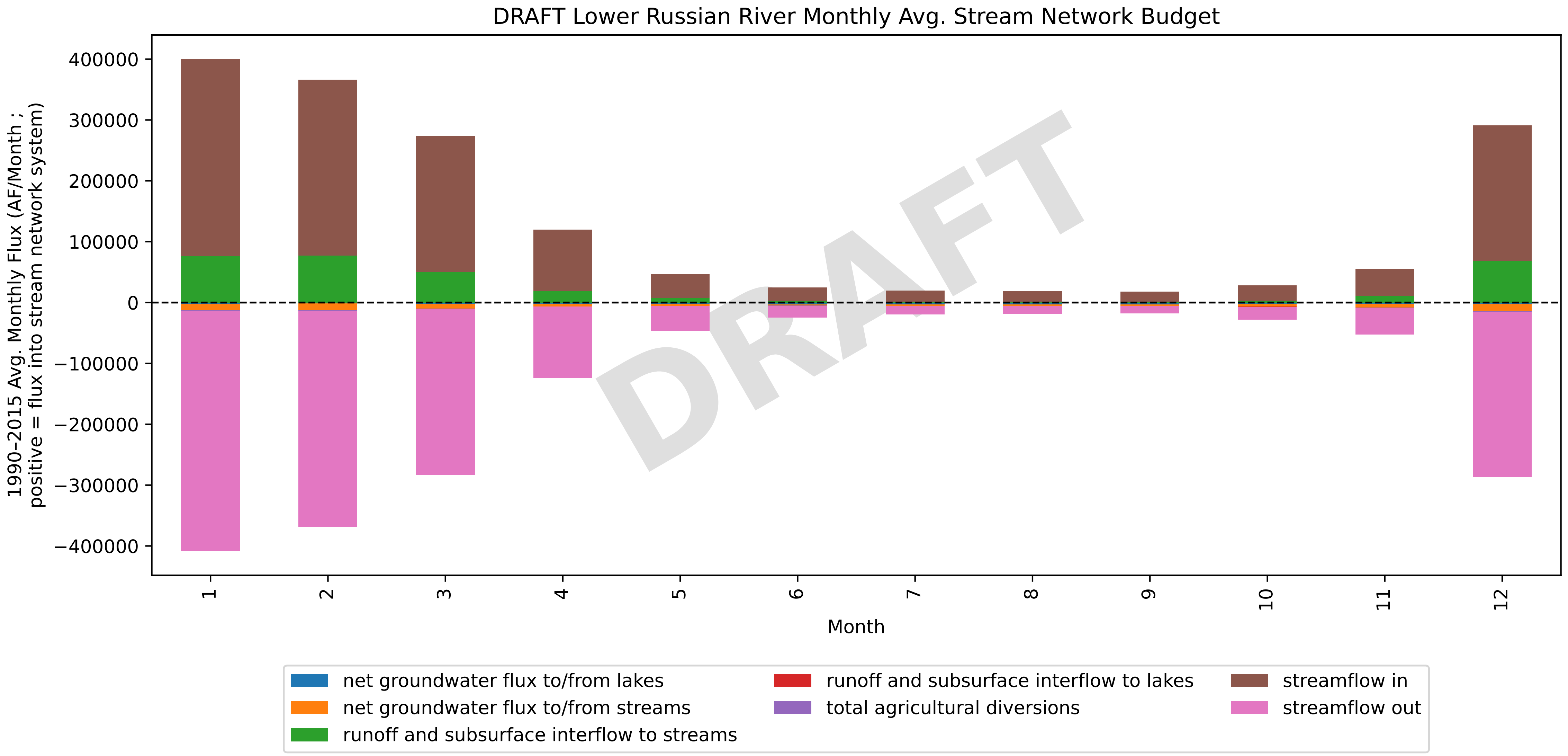
Water Year
net groundwater flux to/from lakes
net groundwater flux to/from streams
runoff and subsurface interflow to streams
runoff and subsurface interflow to lakes
total agricultural diversions
streamflow in
streamflow out


DRAFT Lower Russian River Monthly Avg. Stream Network Budget
1990–2015 Avg. Monthly Flux (AF/Month ;
positive = flux into stream network system)
400000
300000
200000
100000
0
−100000
−200000
−300000
−400000
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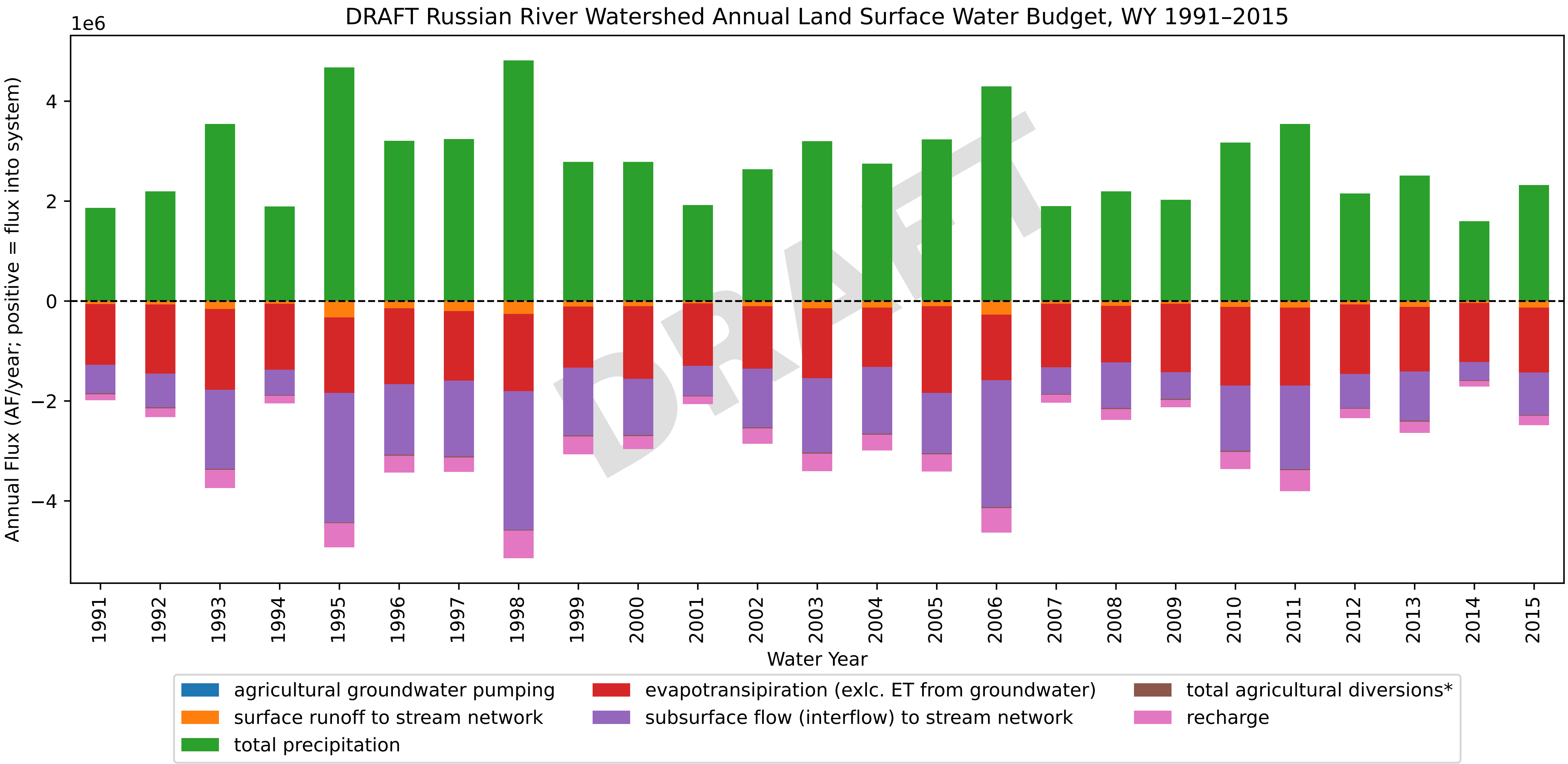
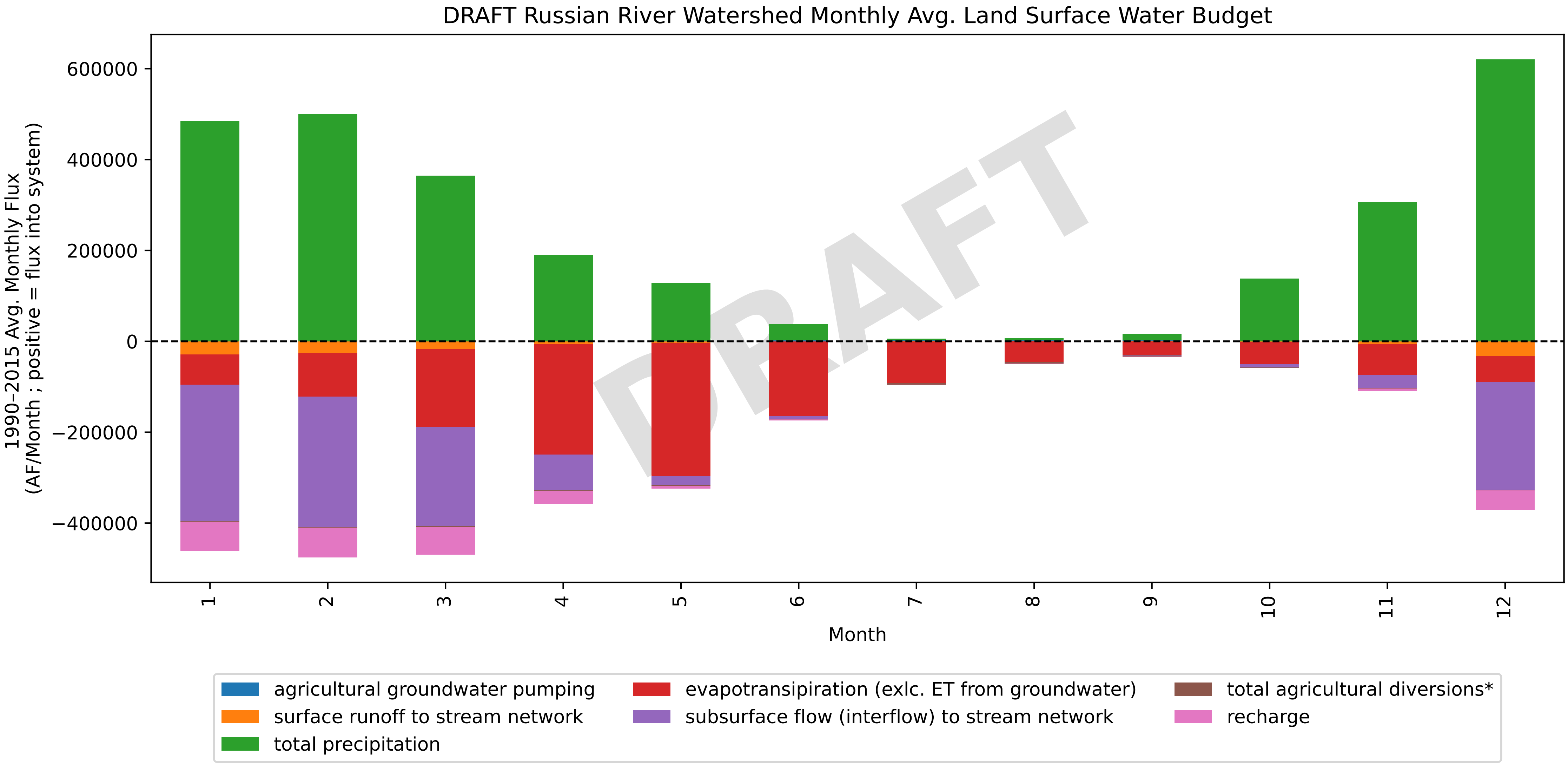
12
Month
DRAFT
net groundwater flux to/from lakes
net groundwater flux to/from streams
runoff and subsurface interflow to streams
runoff and subsurface interflow to lakes
total agricultural diversions
streamflow in
streamflow out



*Note: Agricultural diversions are assumed to be applied at the land surface or in surface ponds



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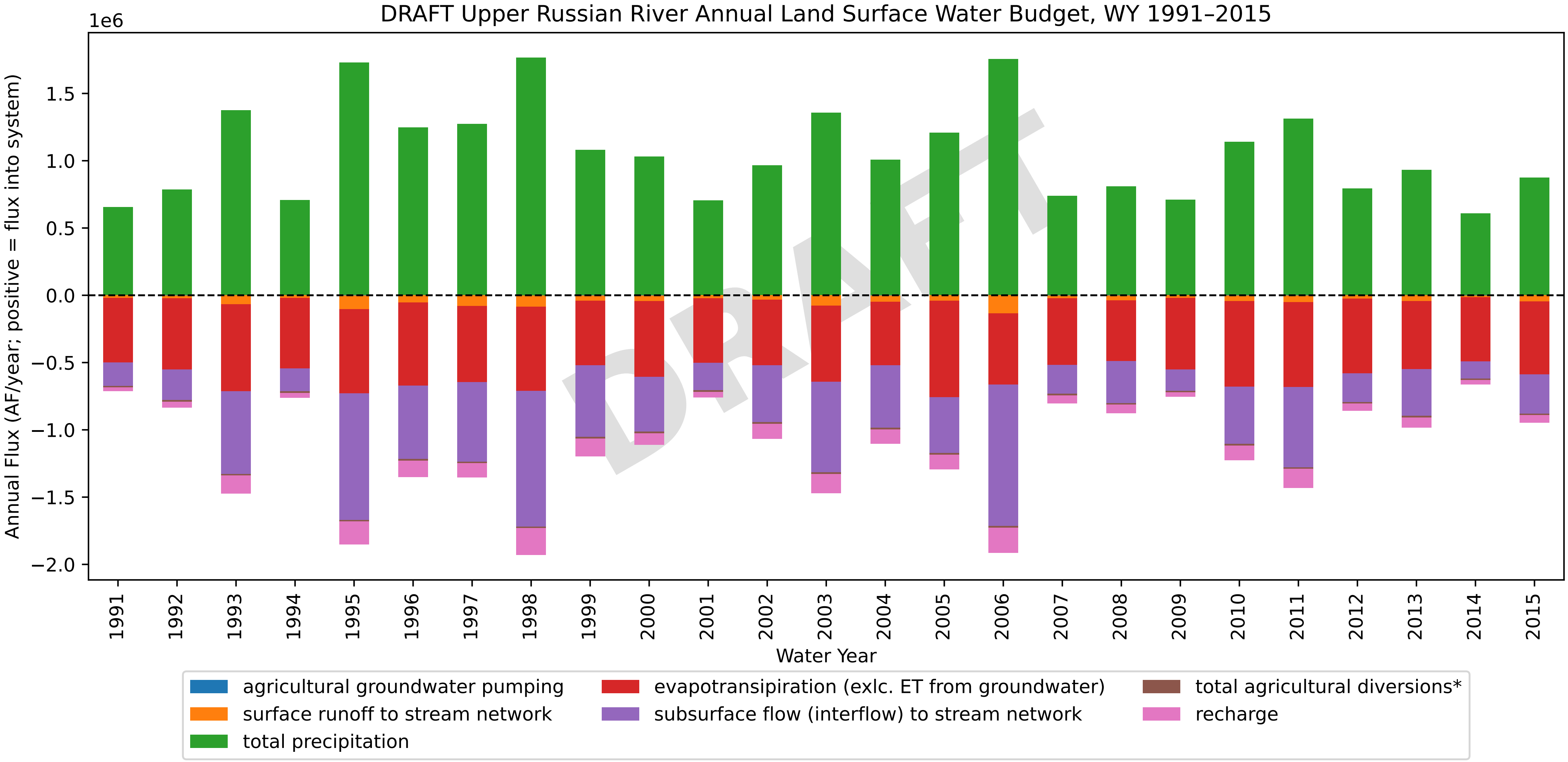

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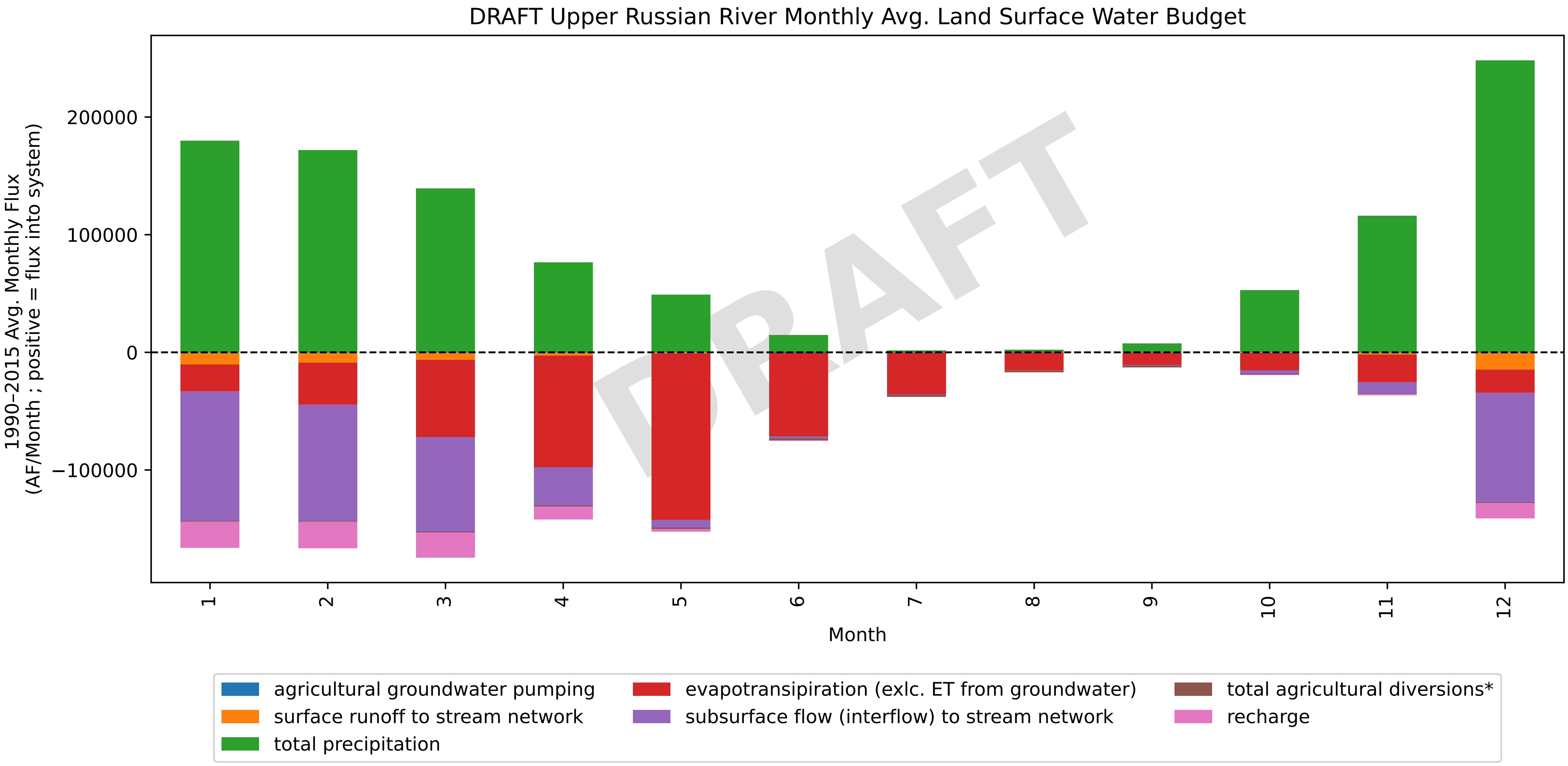

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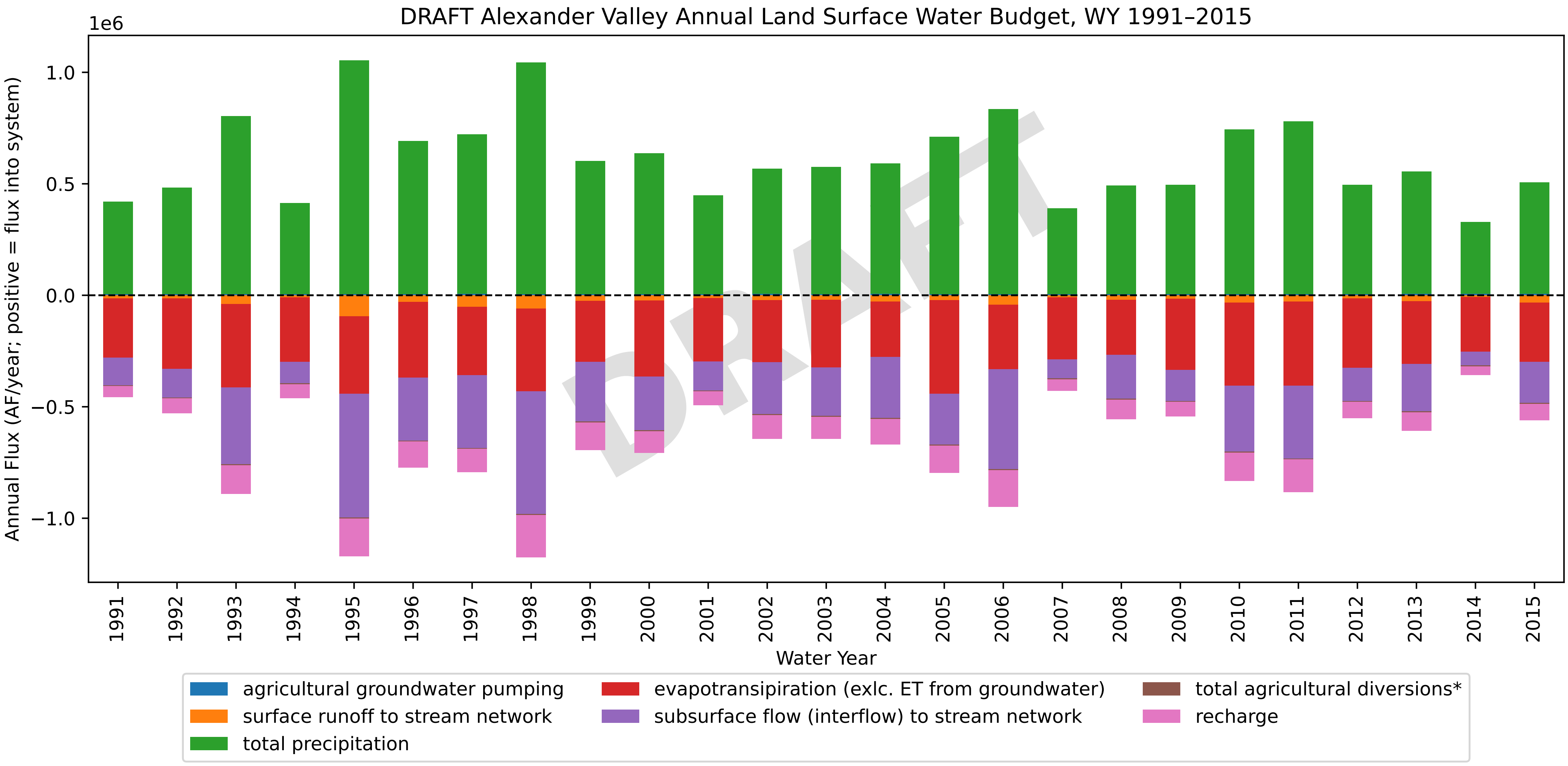

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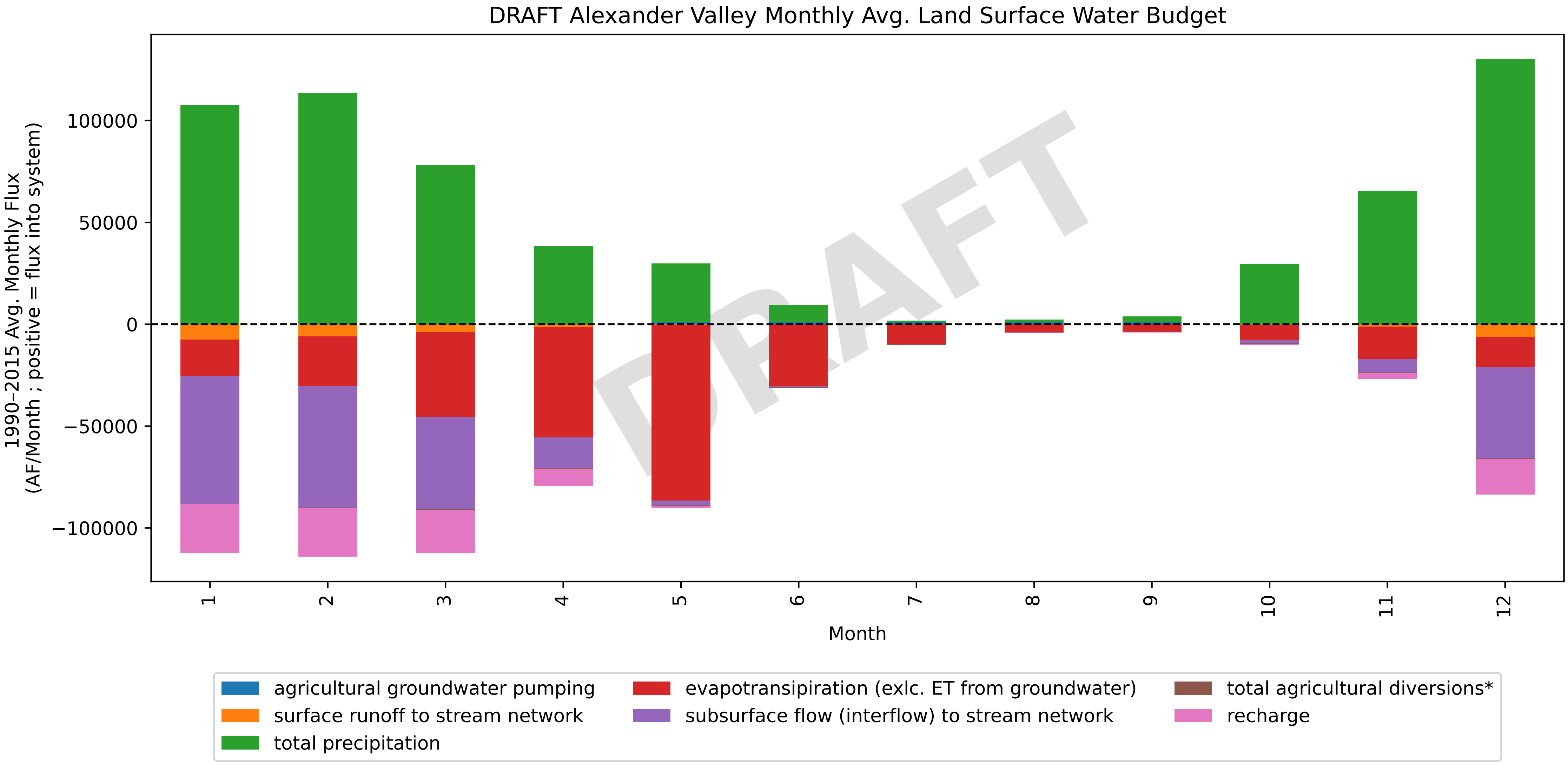

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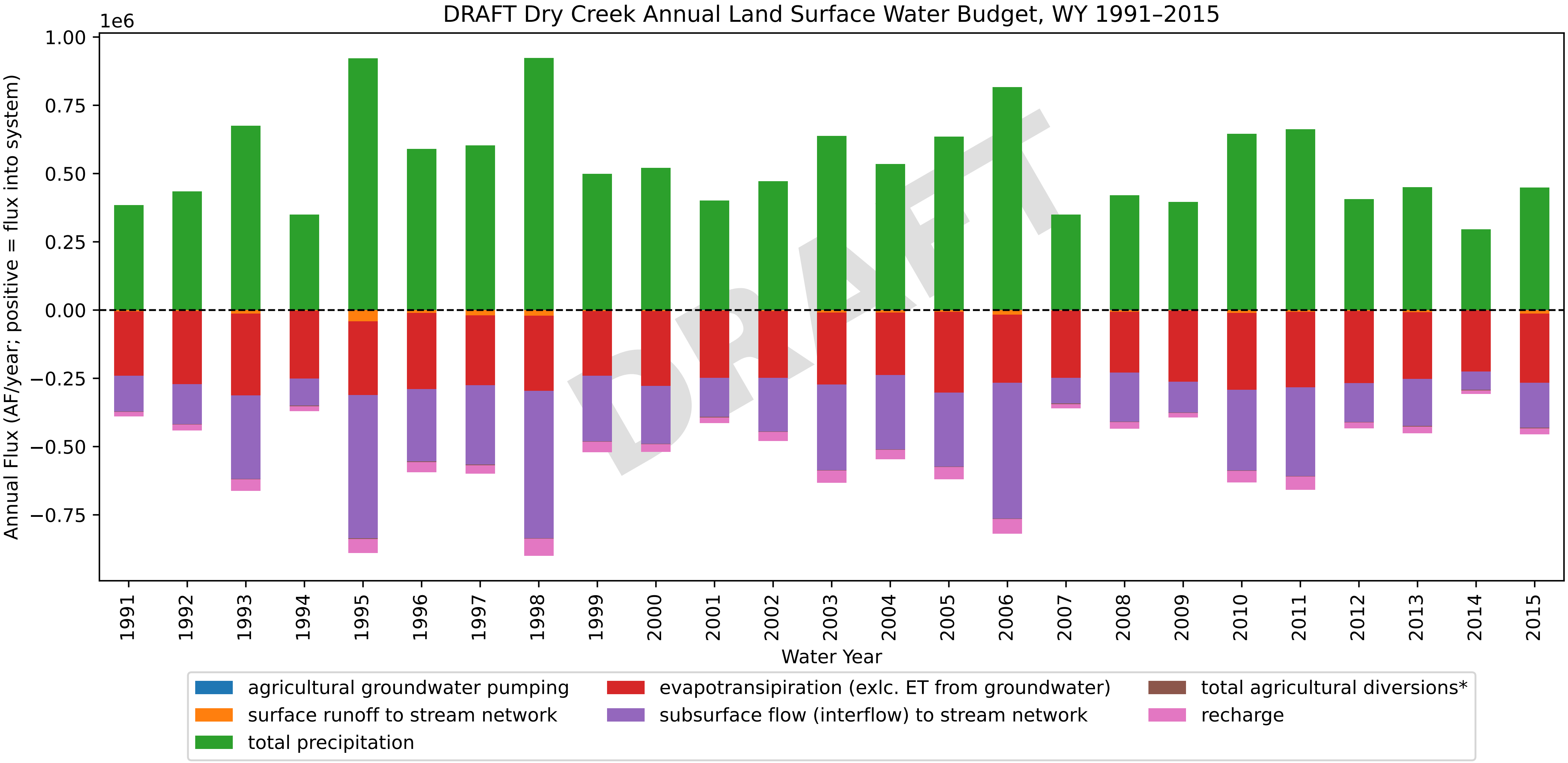

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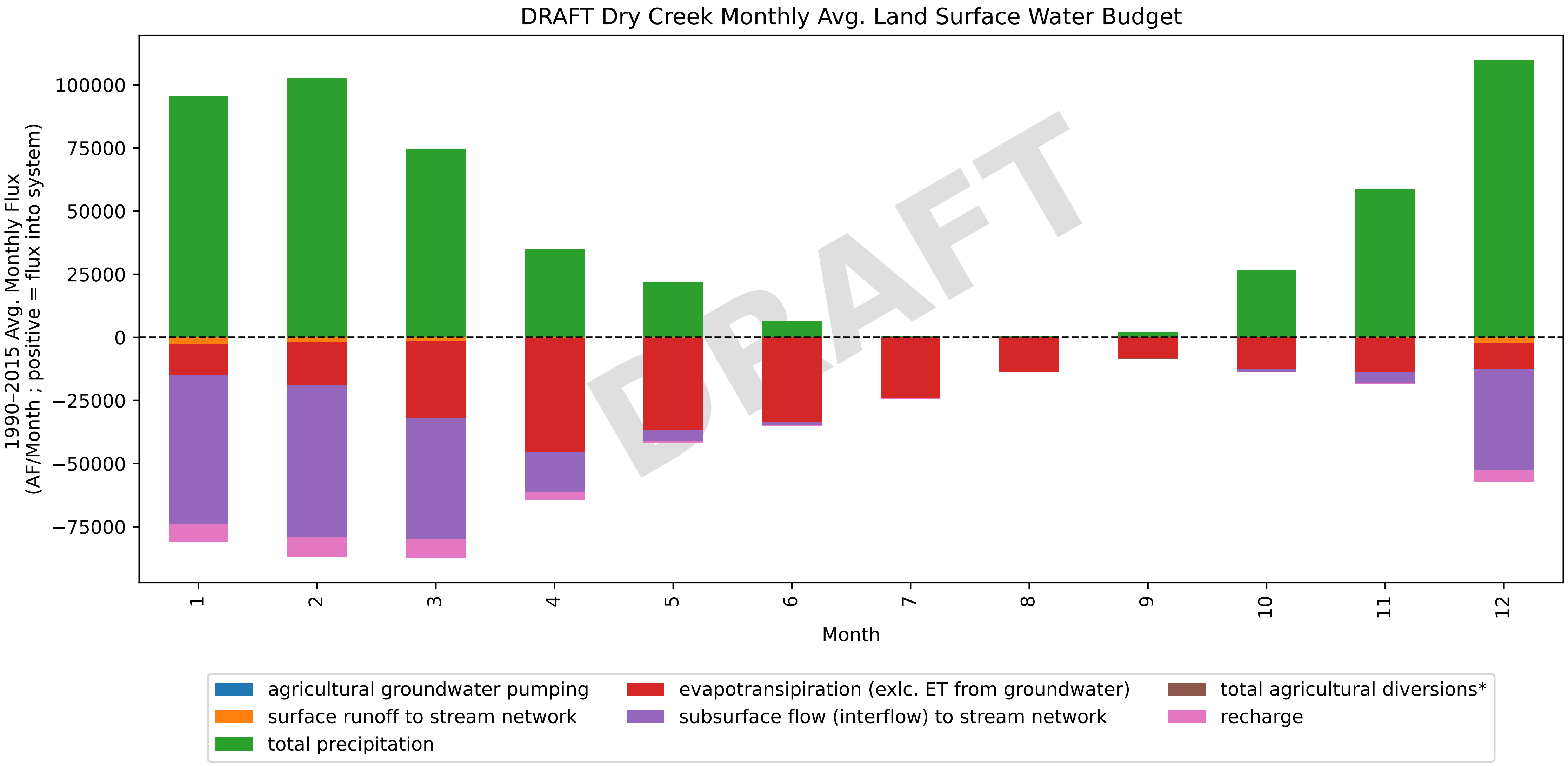

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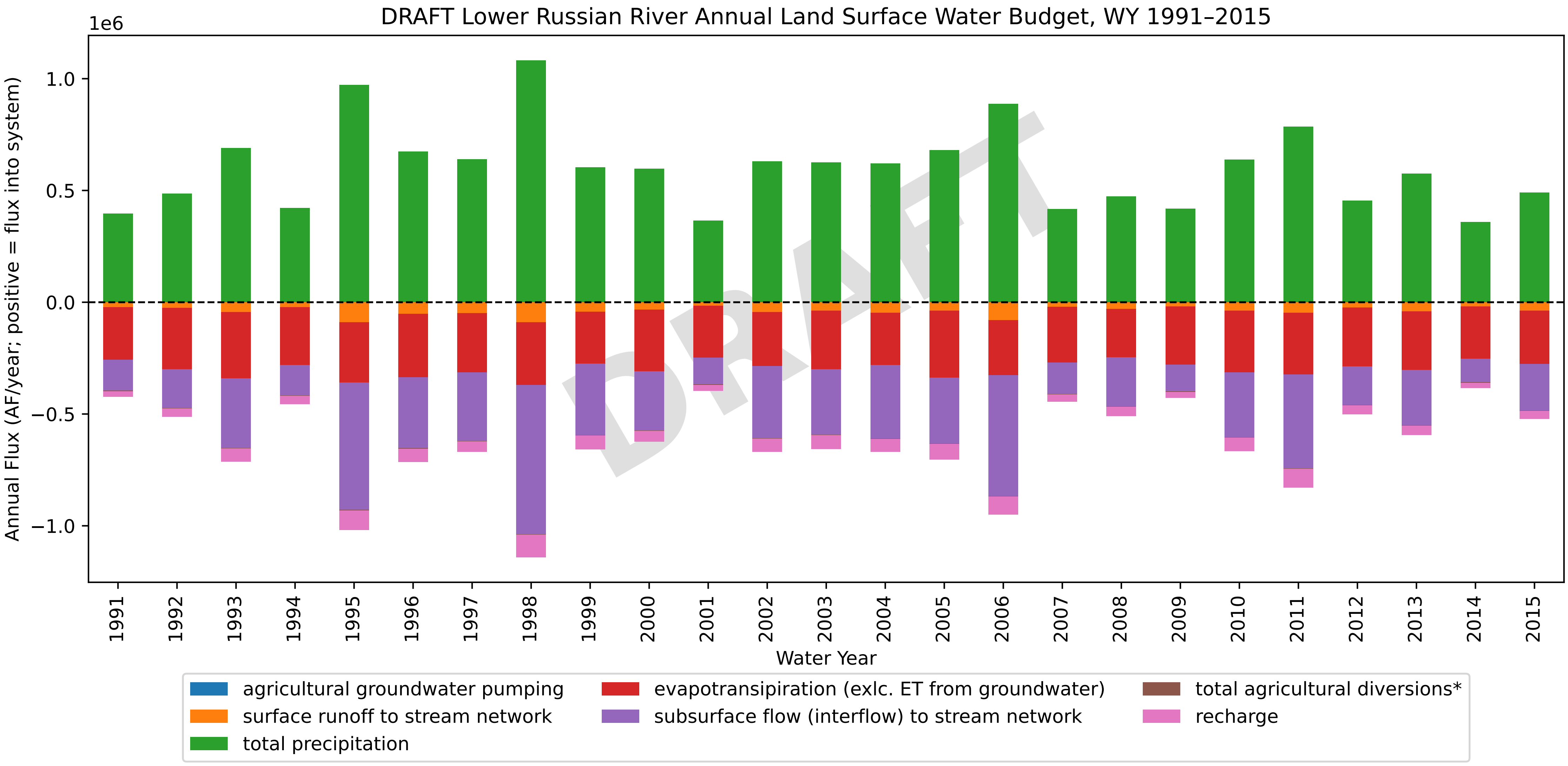

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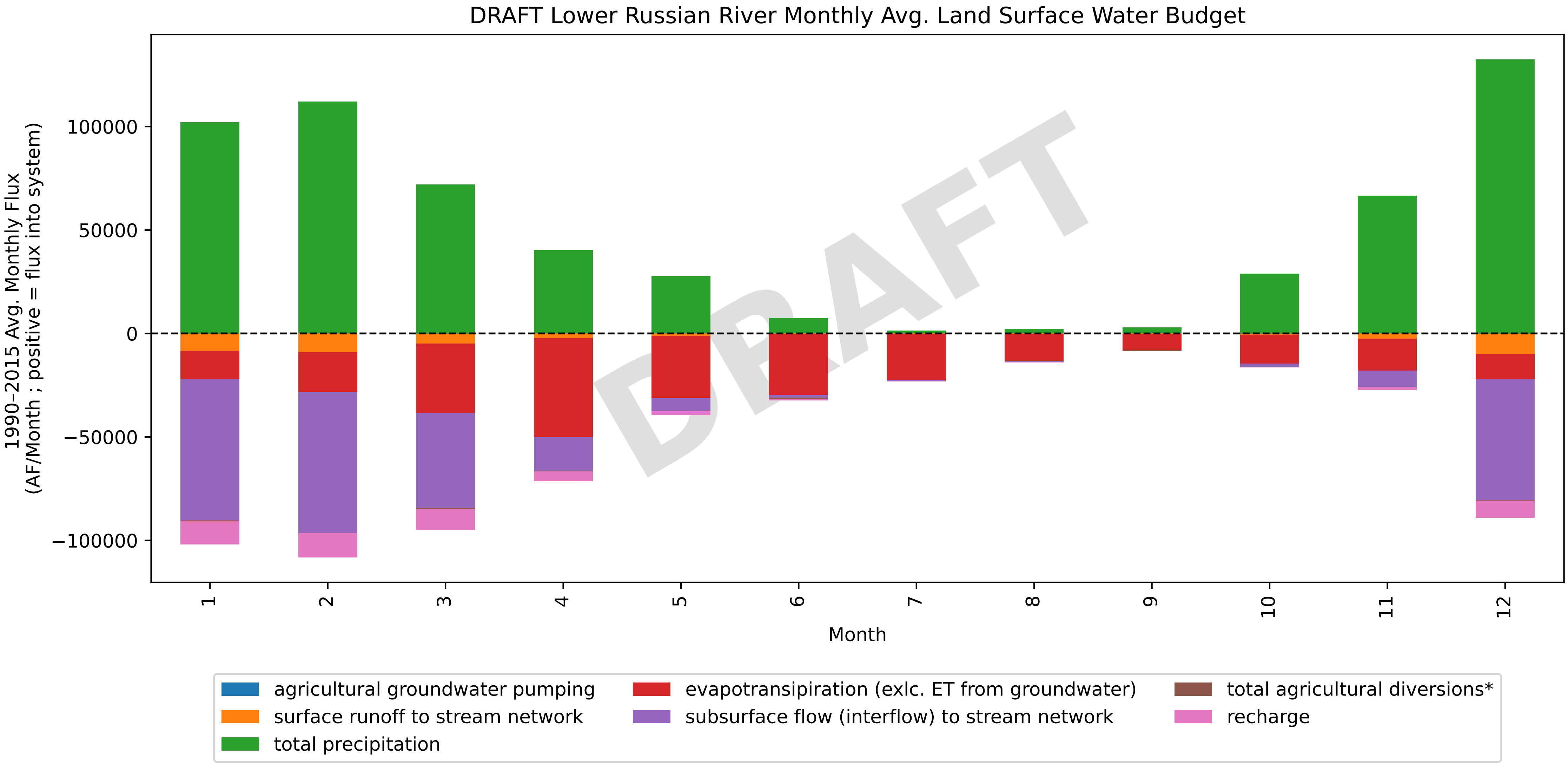

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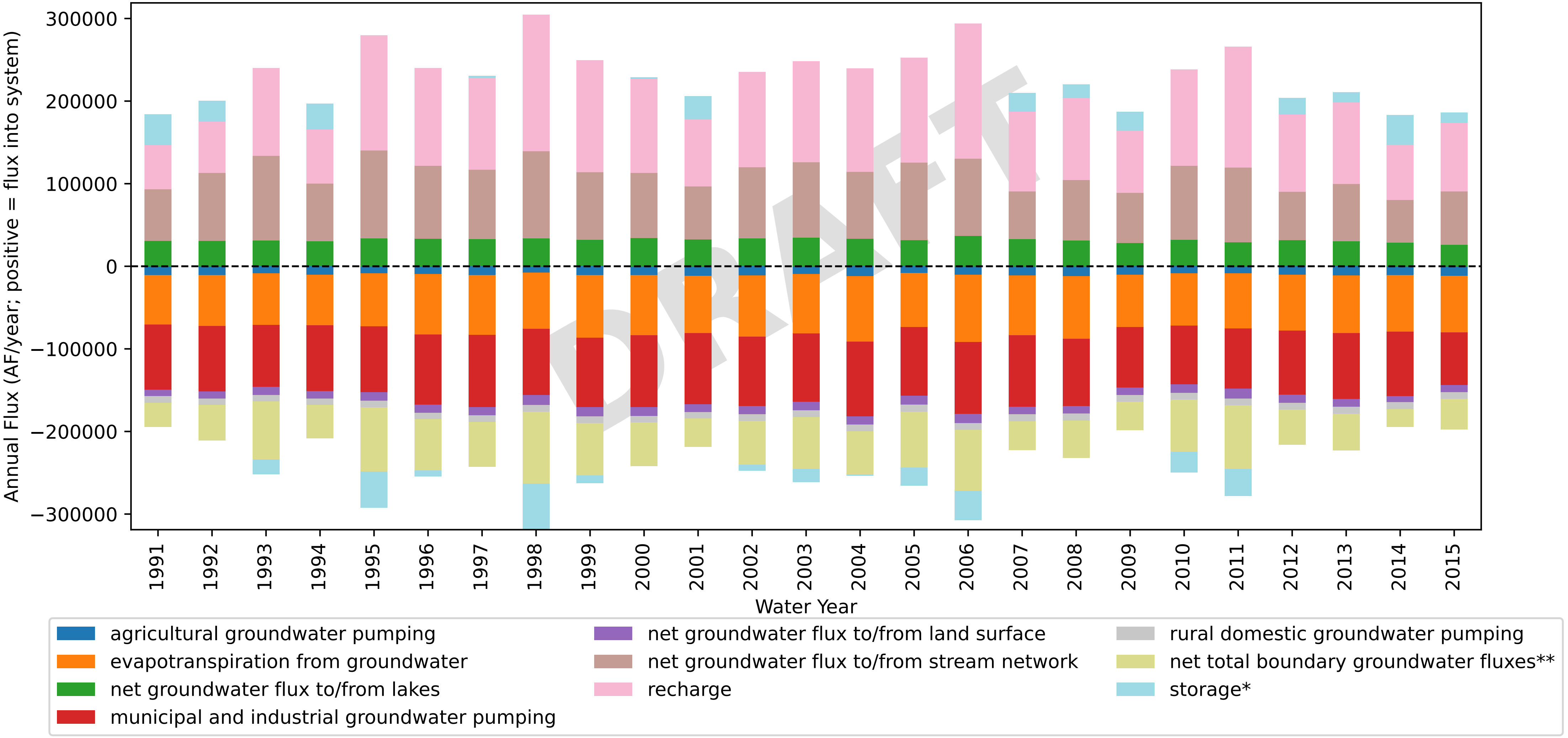
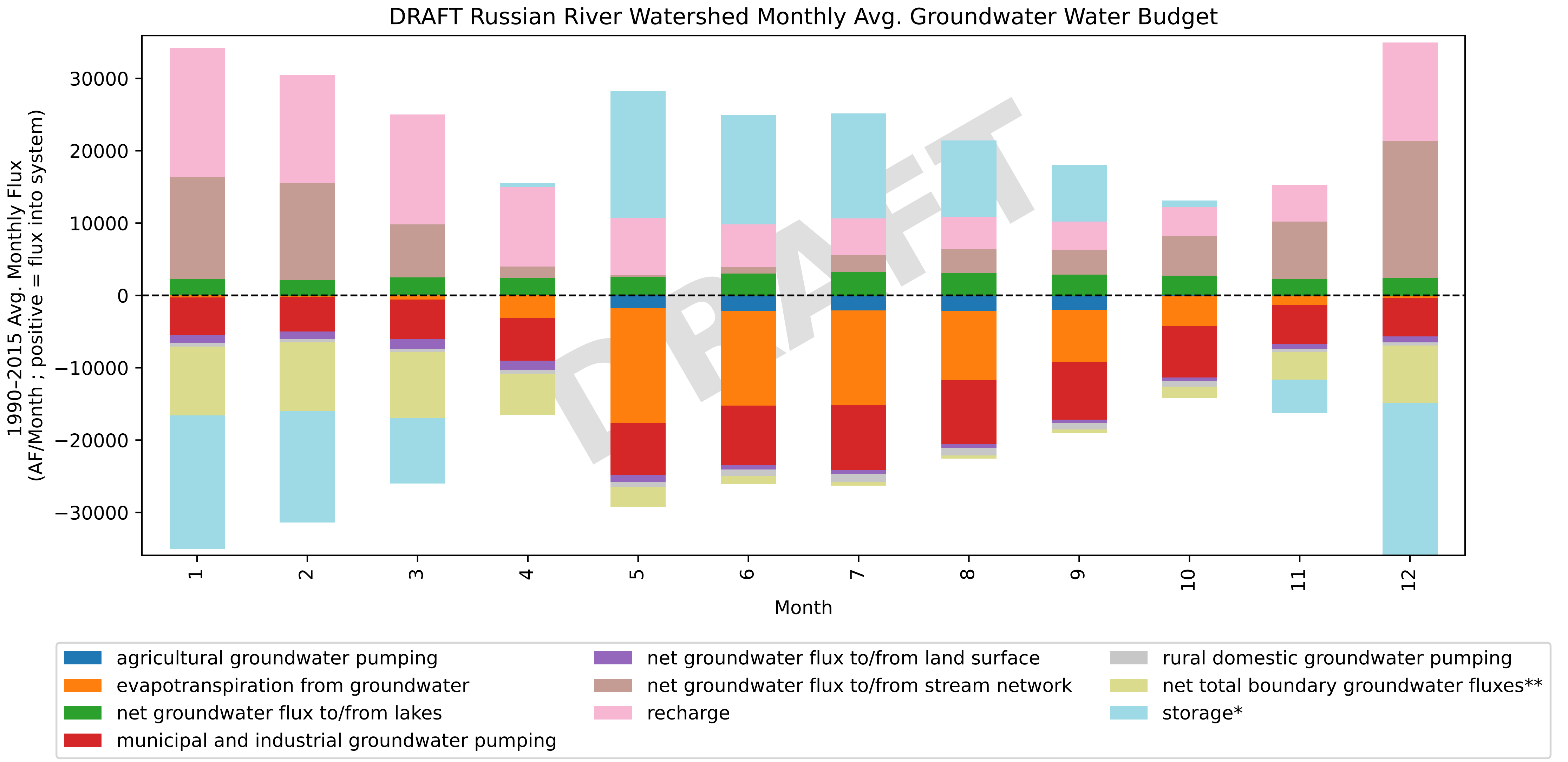
DRAFT Russian River Watershed Annual Groundwater Water Budget, WY 1991–2015



*Note: Positive storage values indicate the volume of water that is released from storage. Negative storage values indicate the volume of water that is partitioned into storage. **Note: Total boundary groundwater fluxes comprise fluxes from other subbasins within the model domain, head dependent boundary fluxes, and constant head fluxes



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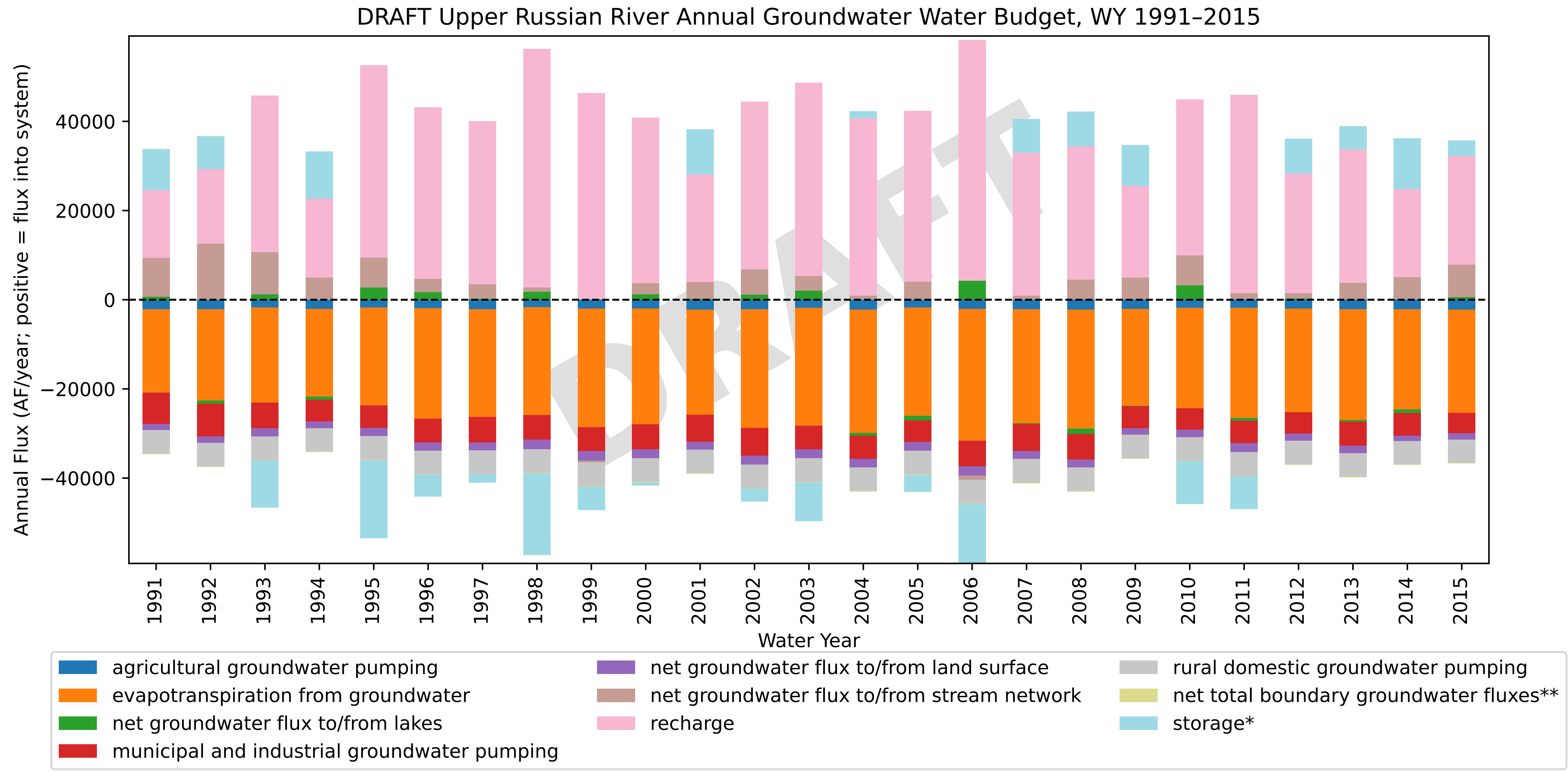

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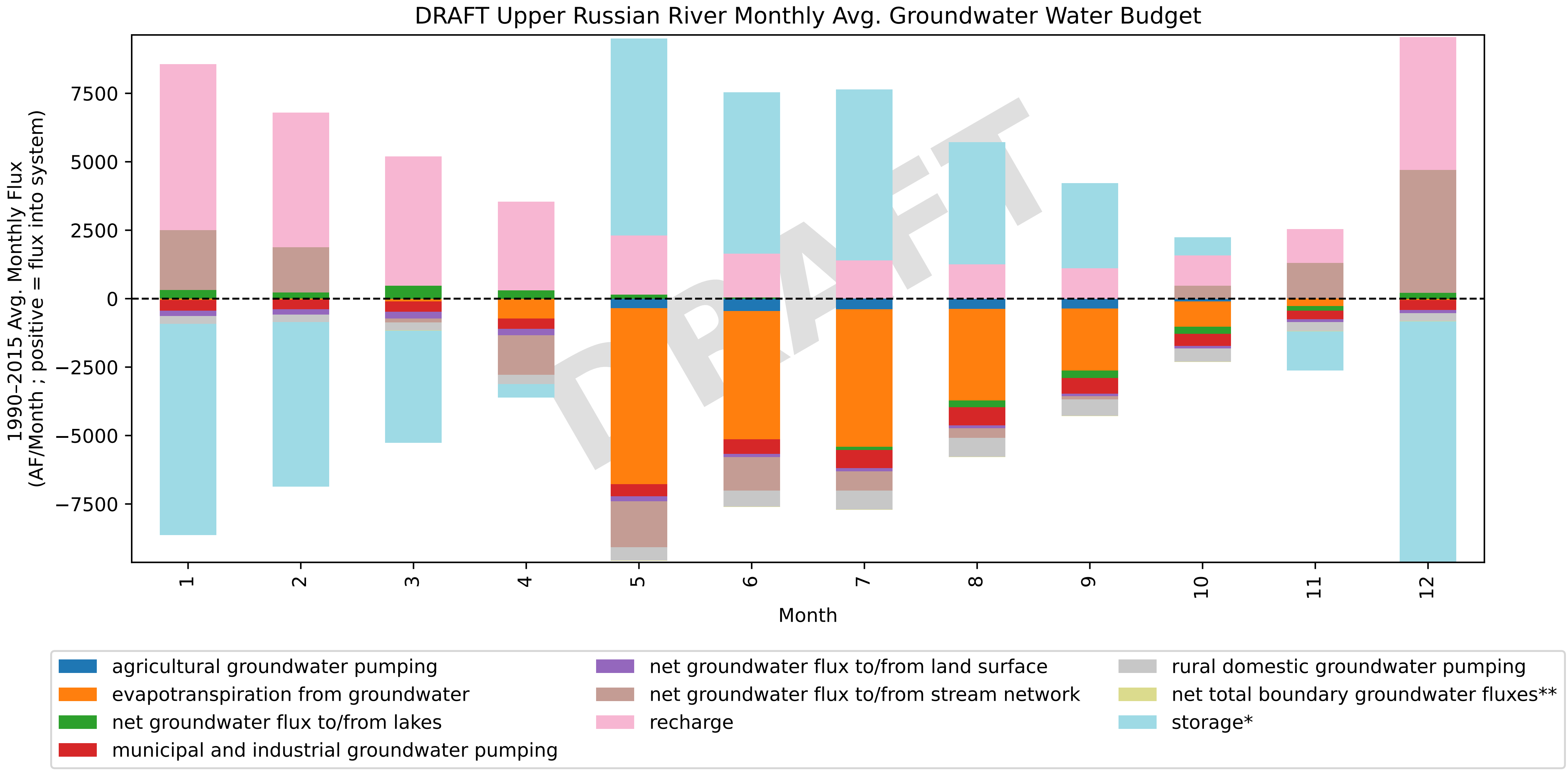

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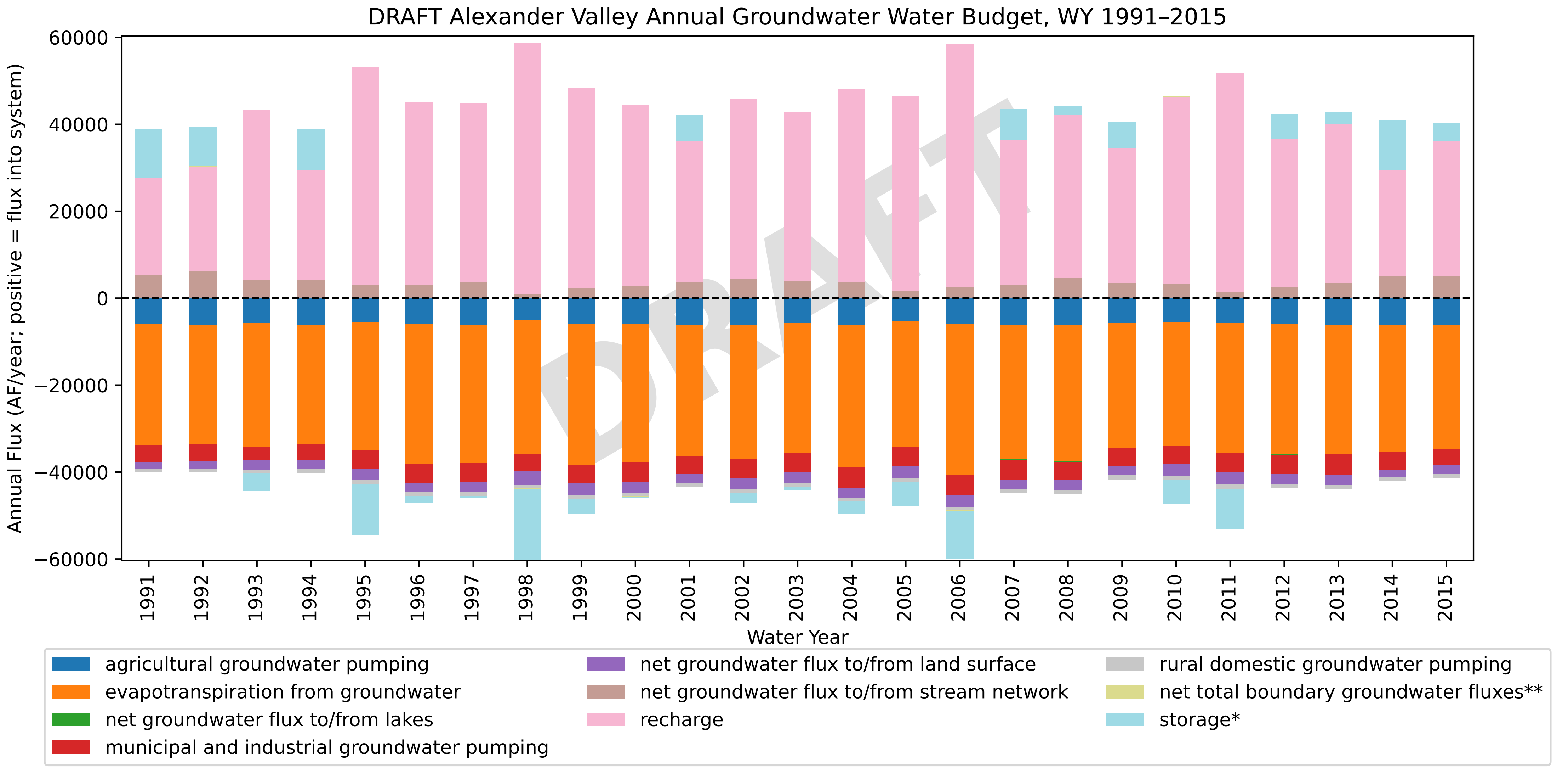

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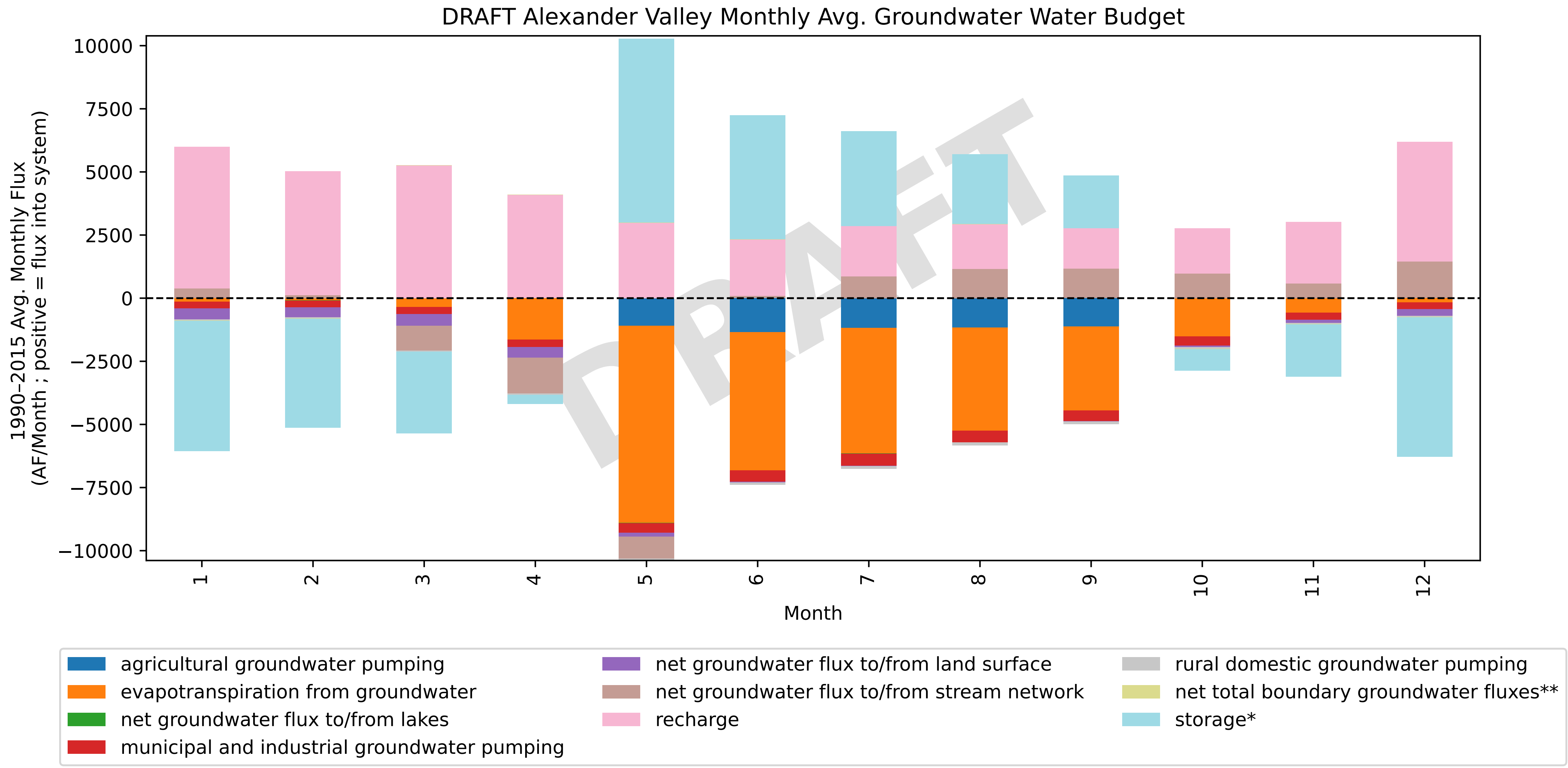

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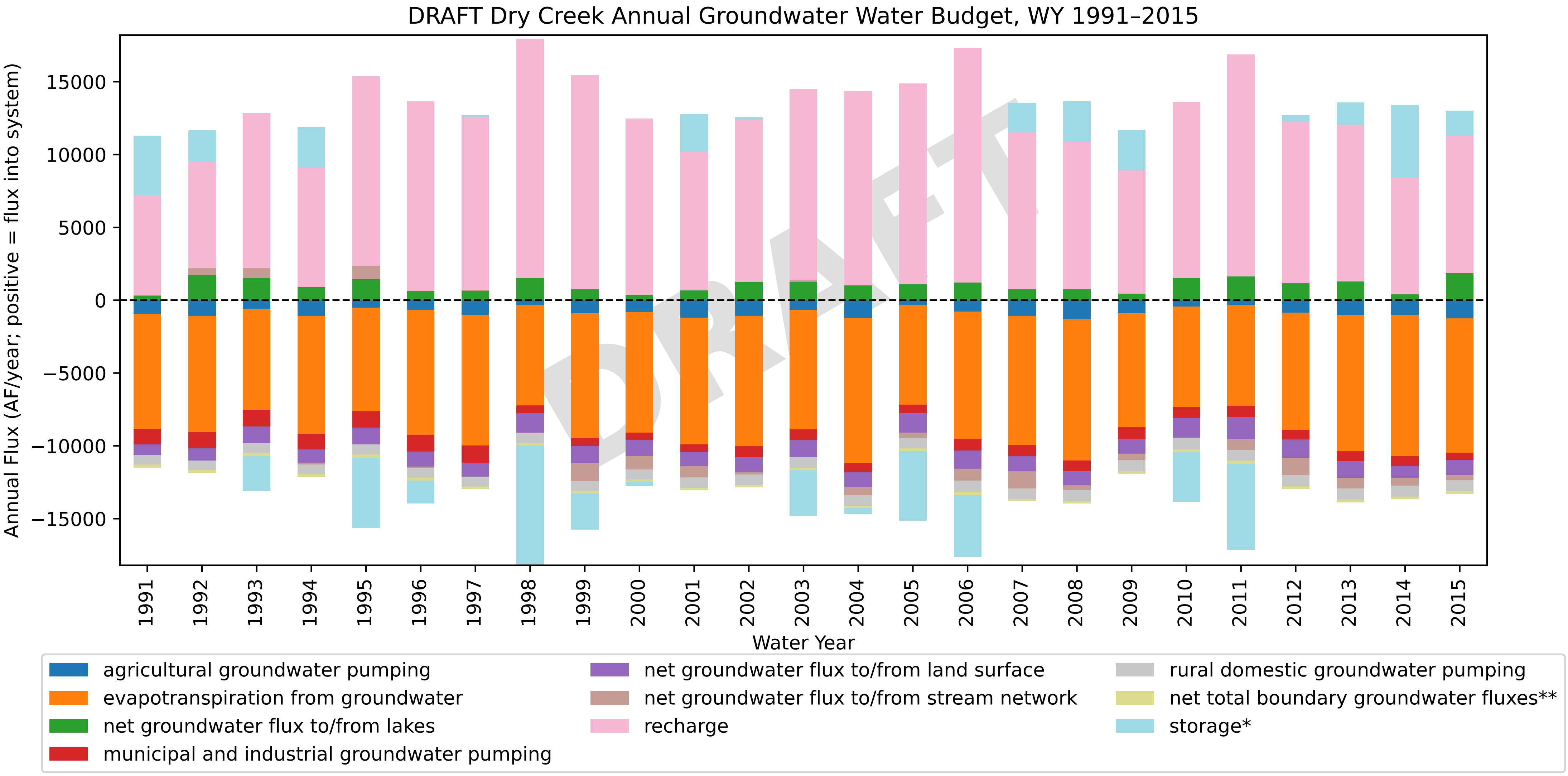

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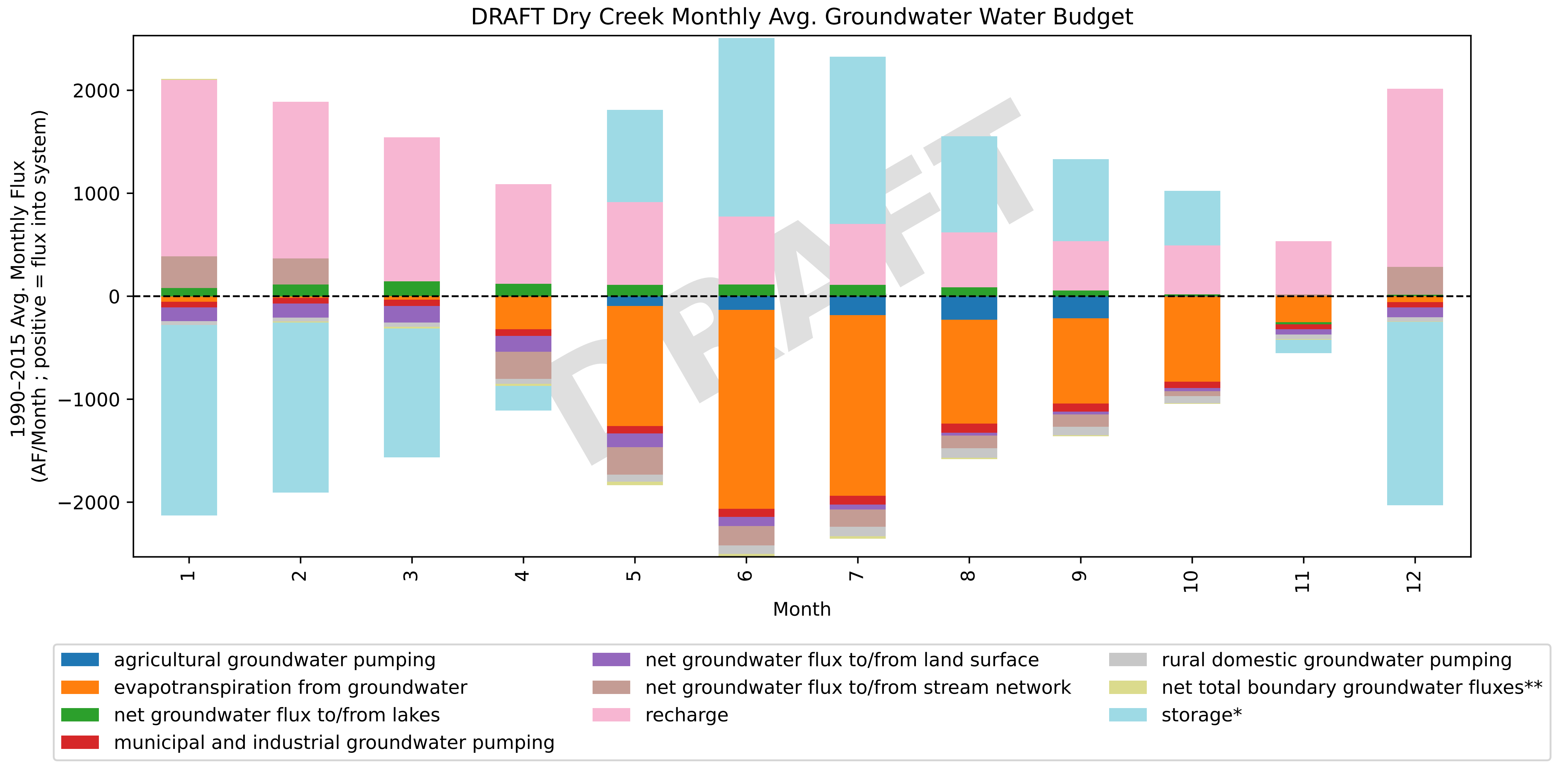

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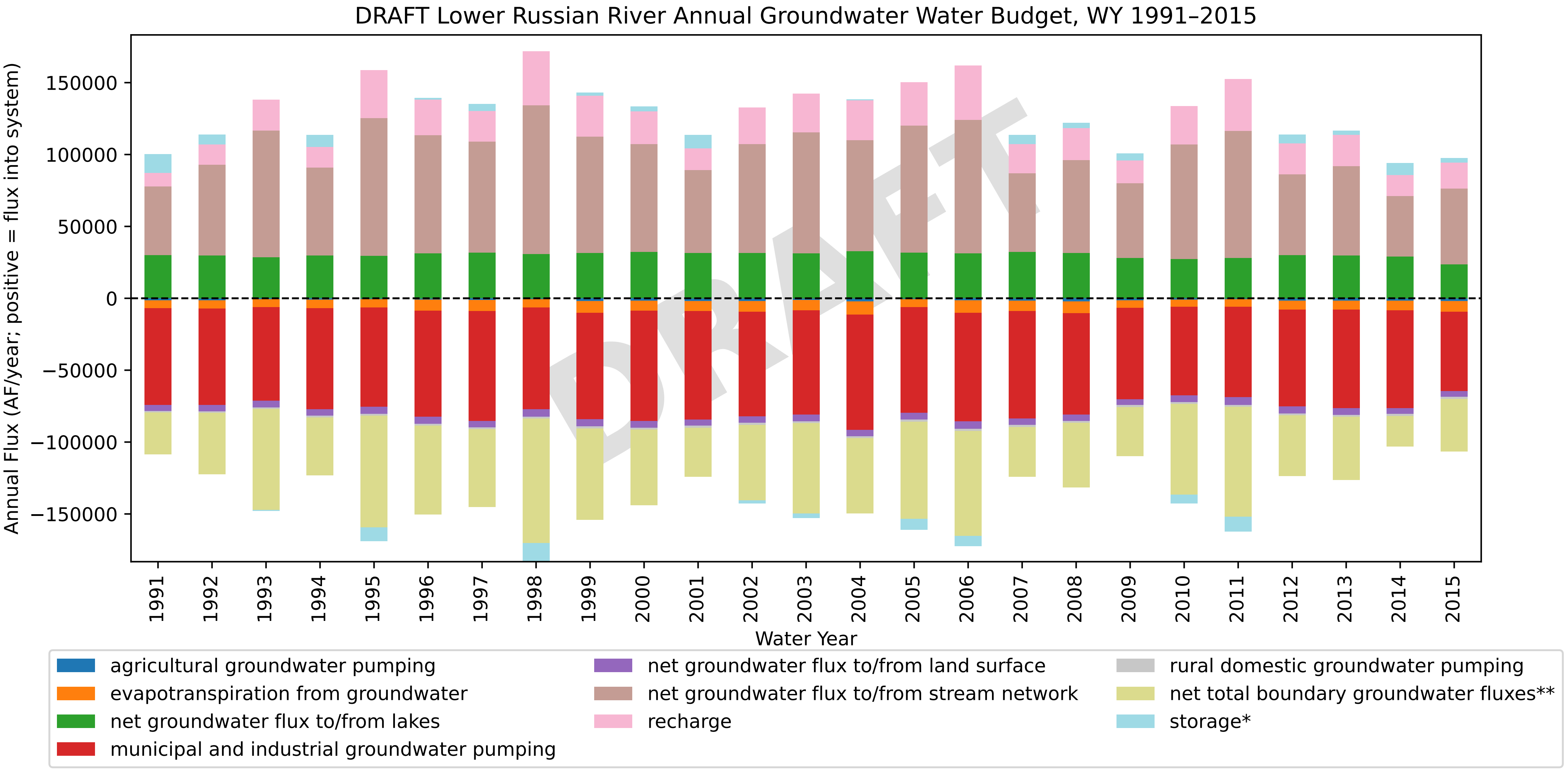

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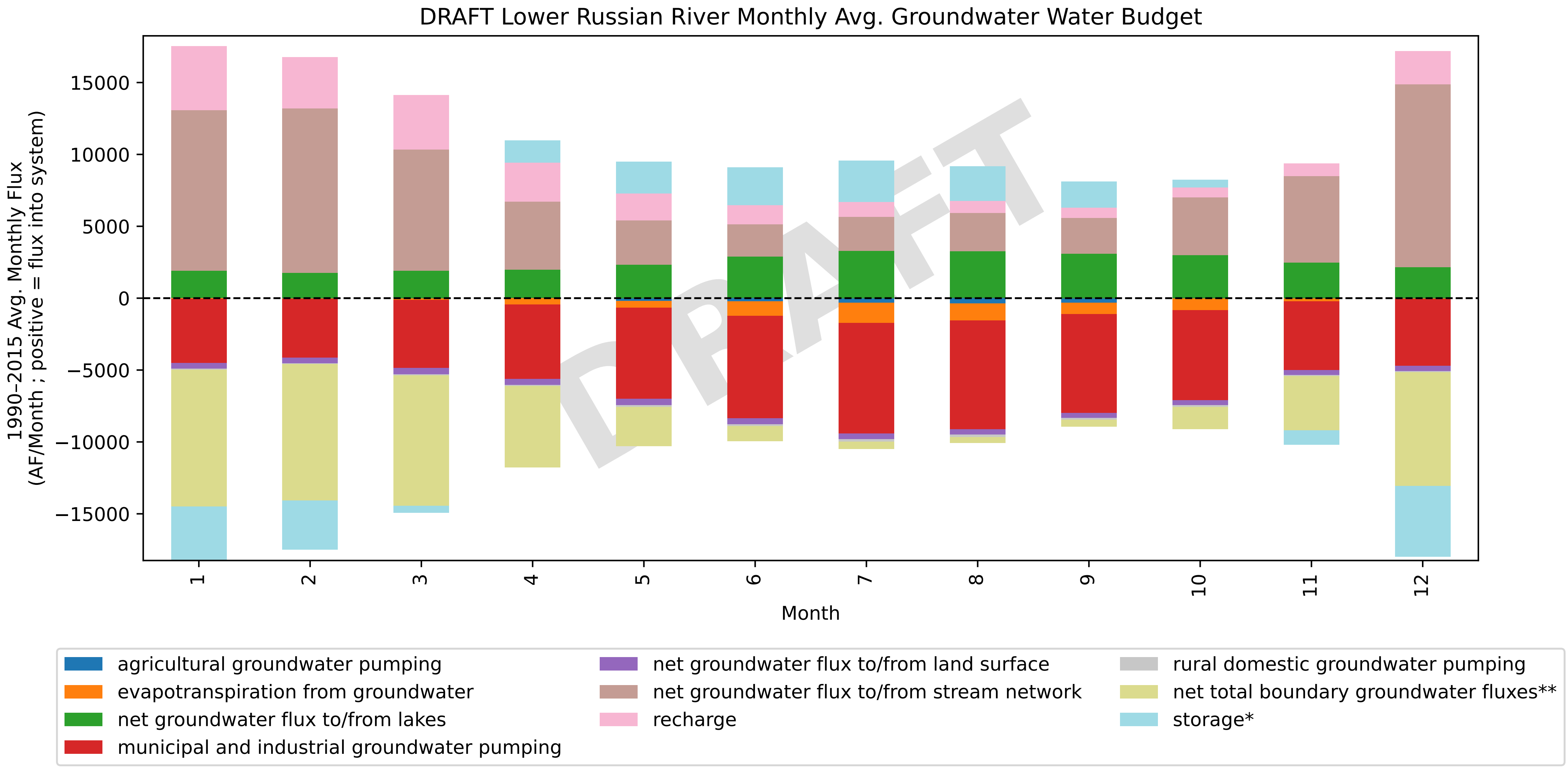

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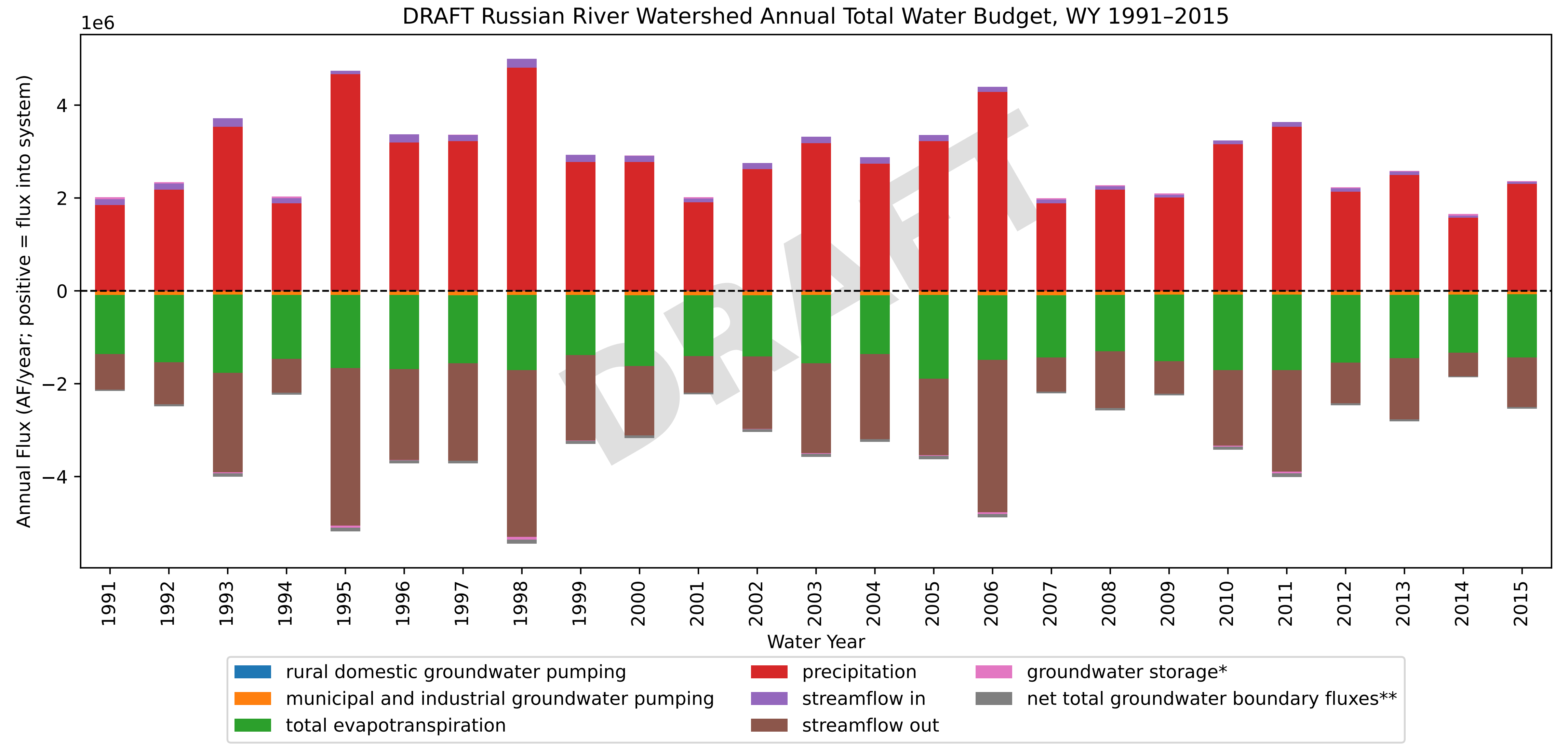
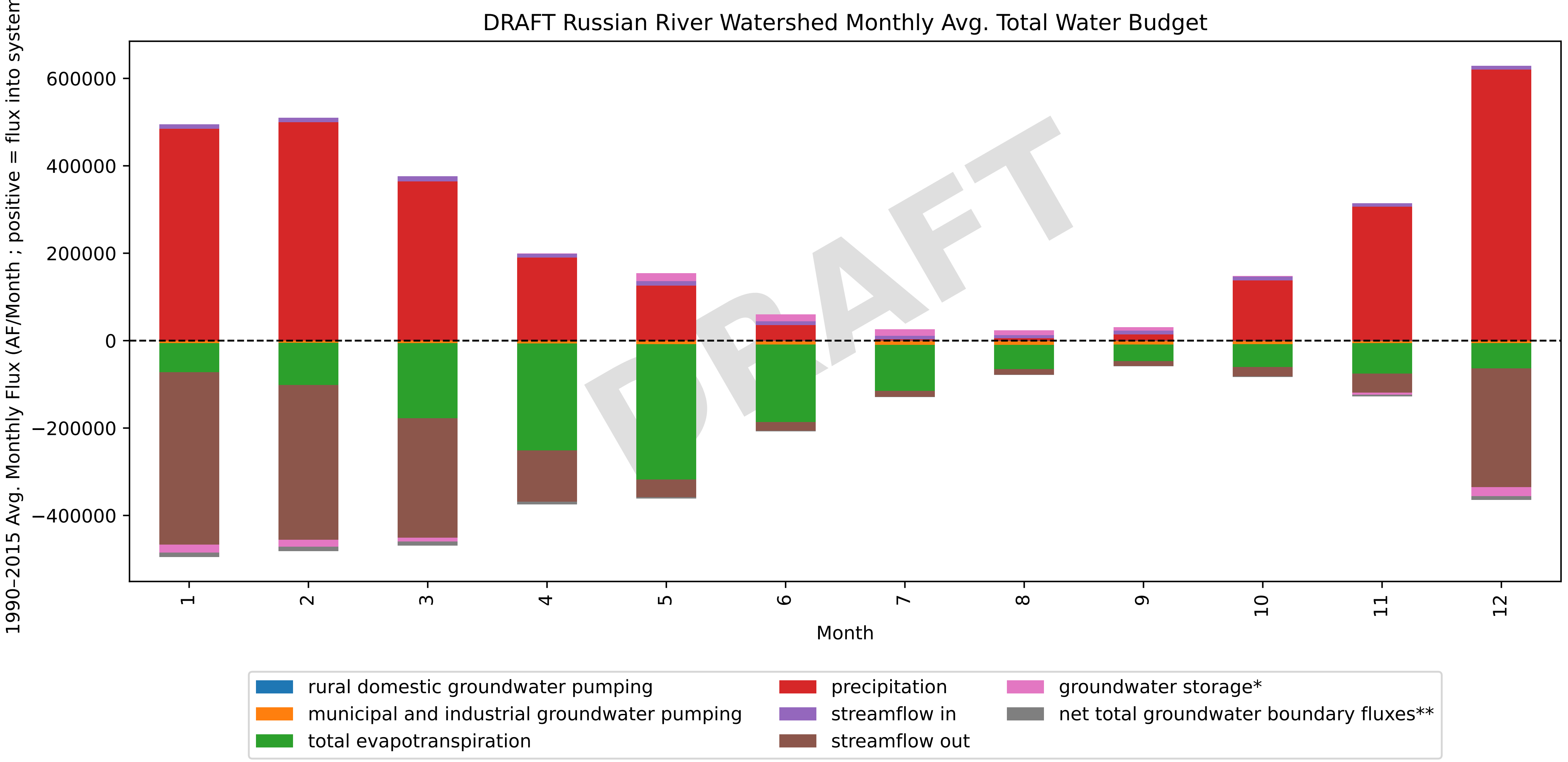
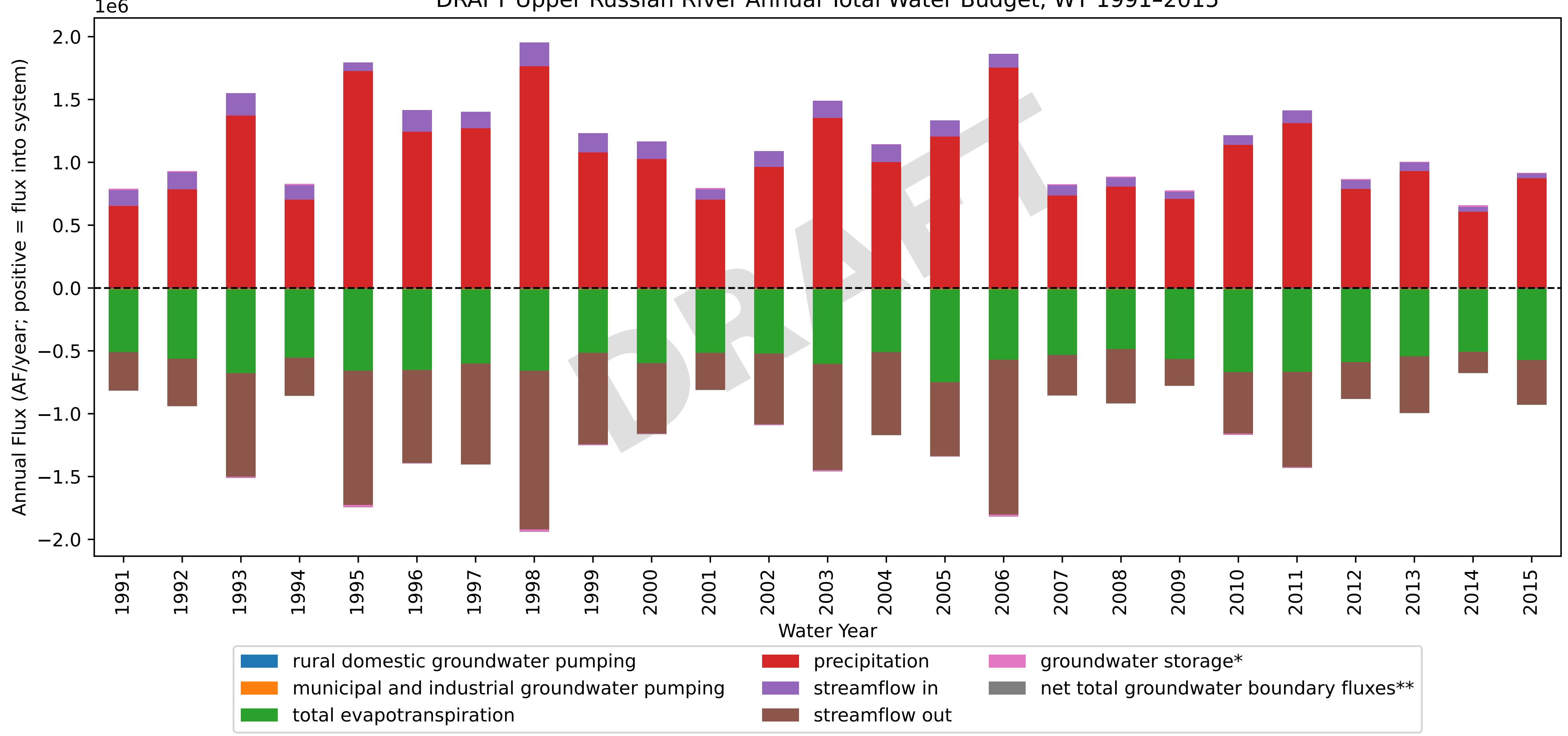


*Note: Positive storage values indicate the volume of groundwater that is released from storage. Negative storage values indicate the volume of groundwater that is partitioned into storage.**Note: Total boundary groundwater fluxes comprise fluxes from other subbasins within the model domain, head dependent boundary fluxes, and constant head fluxes

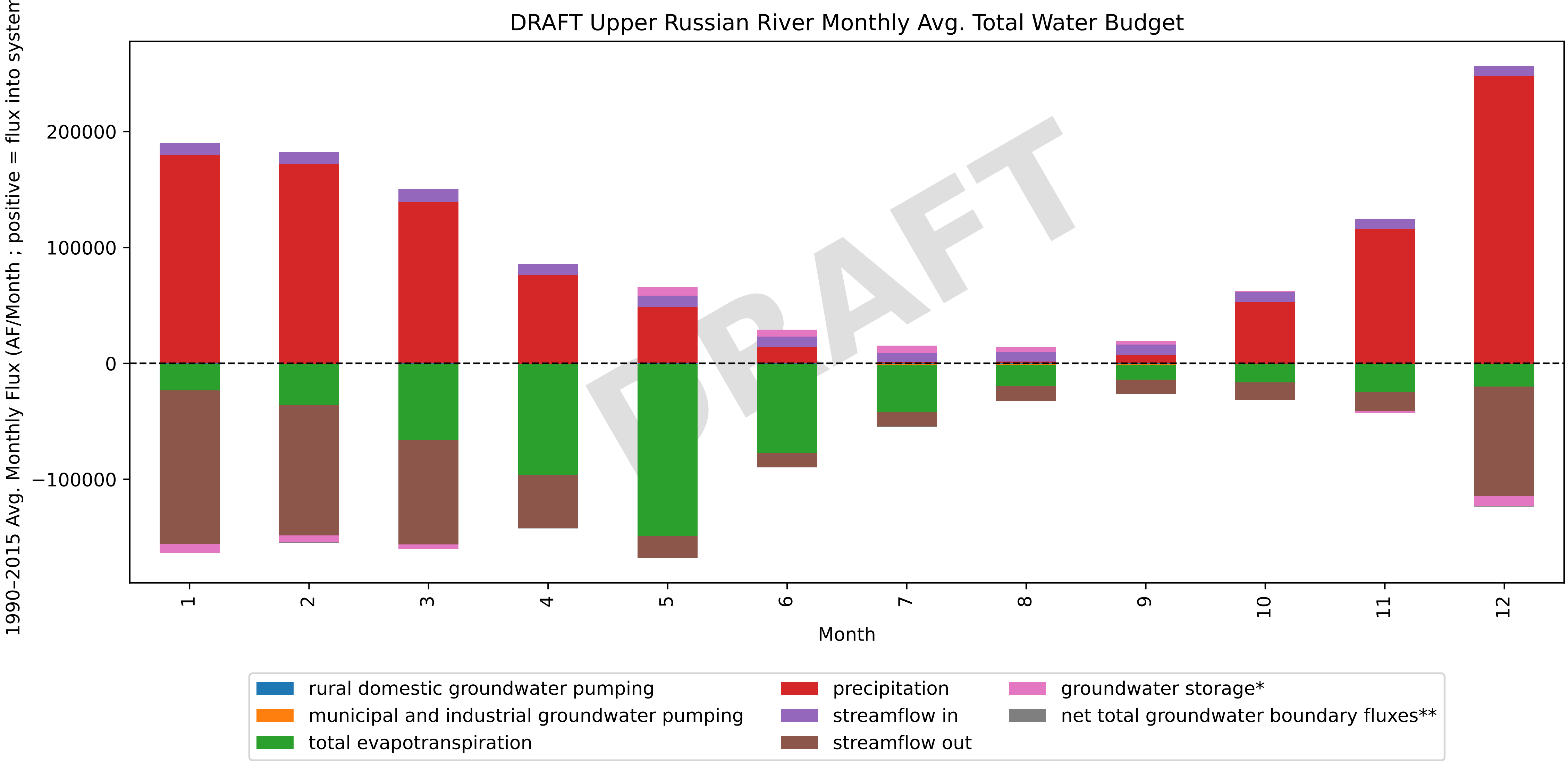


*Note: Positive storage values indicate the volume of groundwater that is released from storage. Negative storage values indicate the volume of groundwater that is partitioned into storage.**Note: Total boundary groundwater fluxes comprise fluxes from other subbasins within the model domain, head dependent boundary fluxes, and constant head fluxes

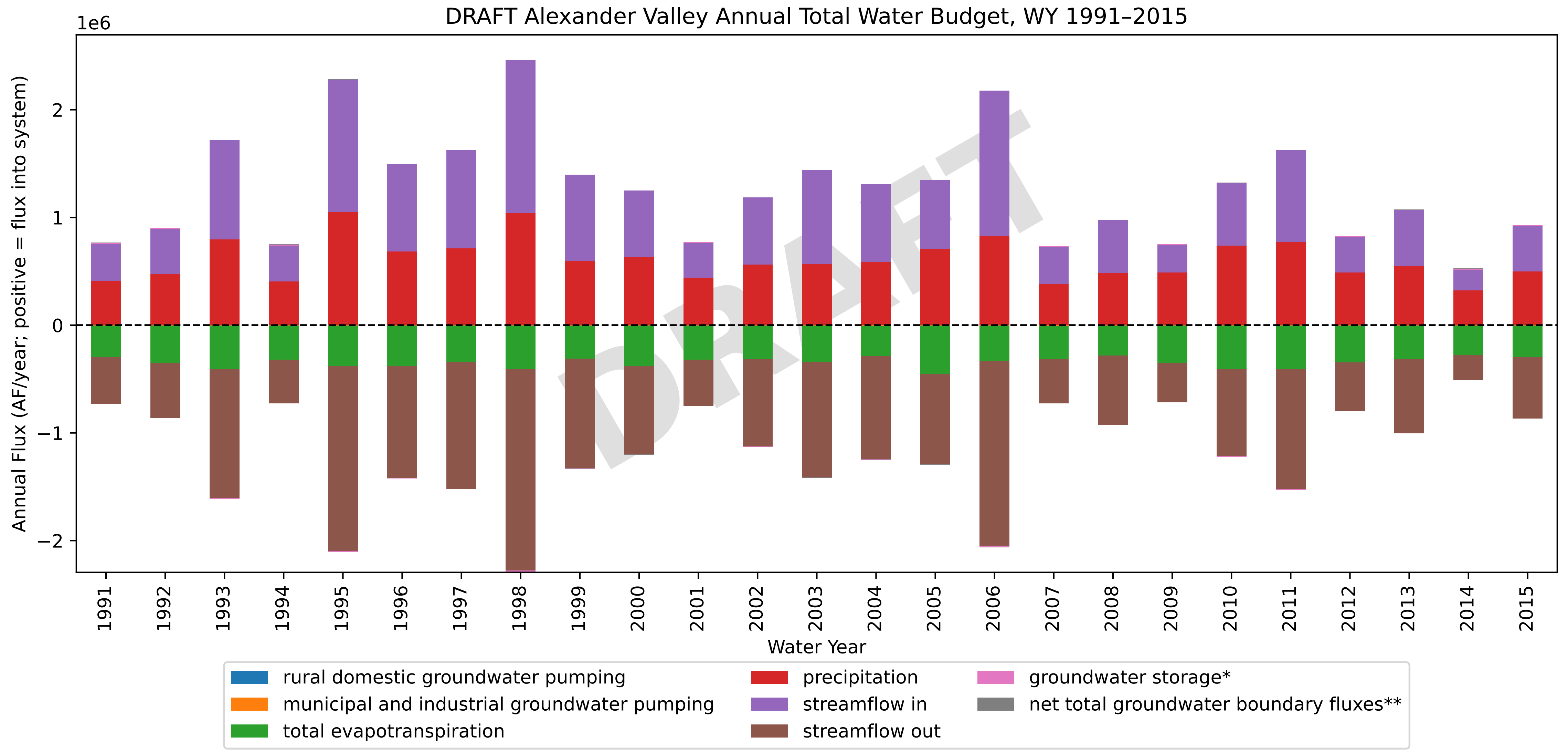
DRAFT Upper Russian River Annual Total Water Budget, WY 1991–2015



*Note: Positive storage values indicate the volume of groundwater that is released from storage. Negative storage values indicate the volume of groundwater that is partitioned into storage.**Note: Total boundary groundwater fluxes comprise fluxes from other subbasins within the model domain, head dependent boundary fluxes, and constant head fluxes



*Note: Positive storage values indicate the volume of groundwater that is released from storage. Negative storage values indicate the volume of groundwater that is partitioned into storage.**Note: Total boundary groundwater fluxes comprise fluxes from other subbasins within the model domain, head dependent boundary fluxes, and constant head fluxes



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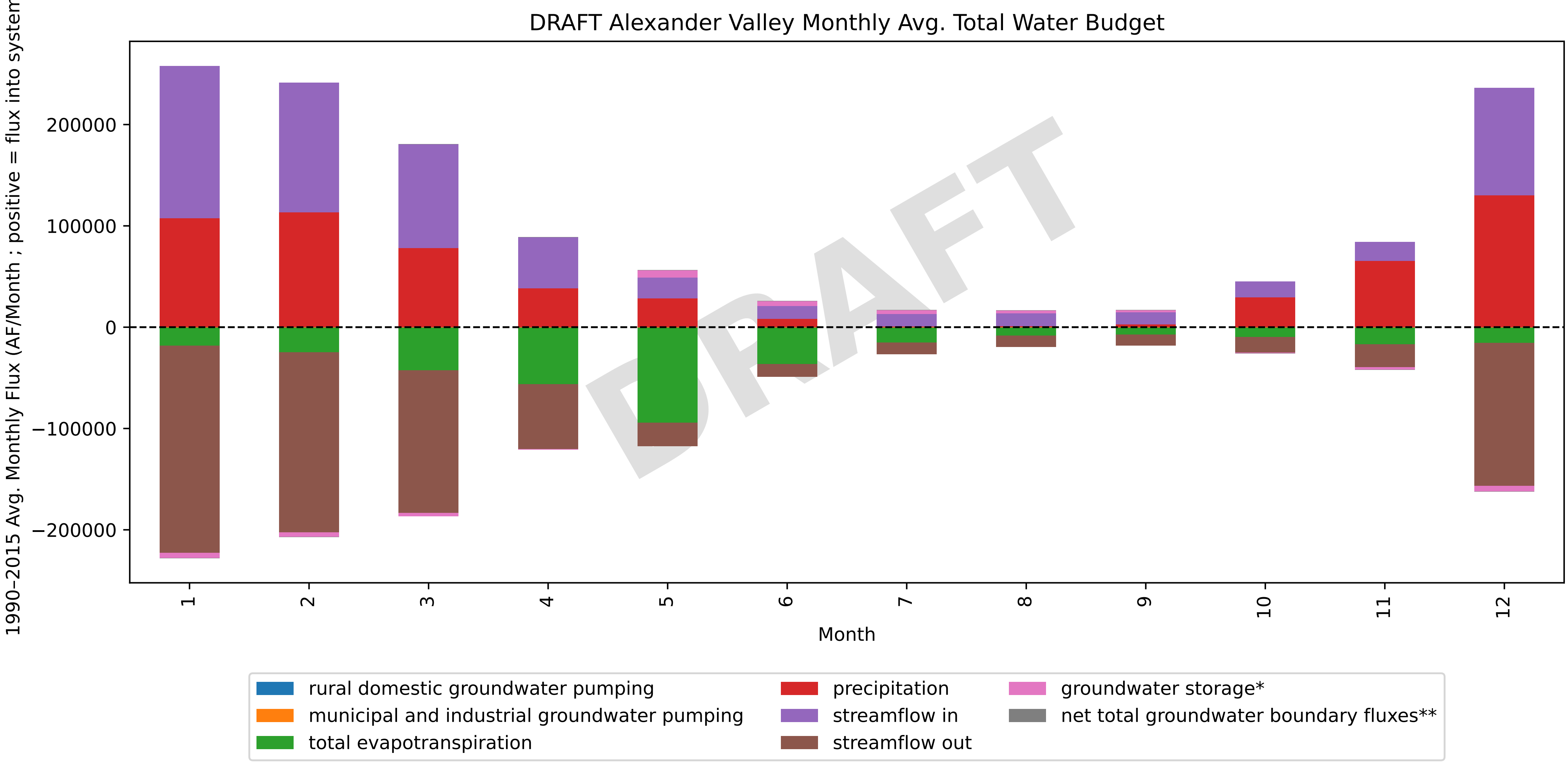

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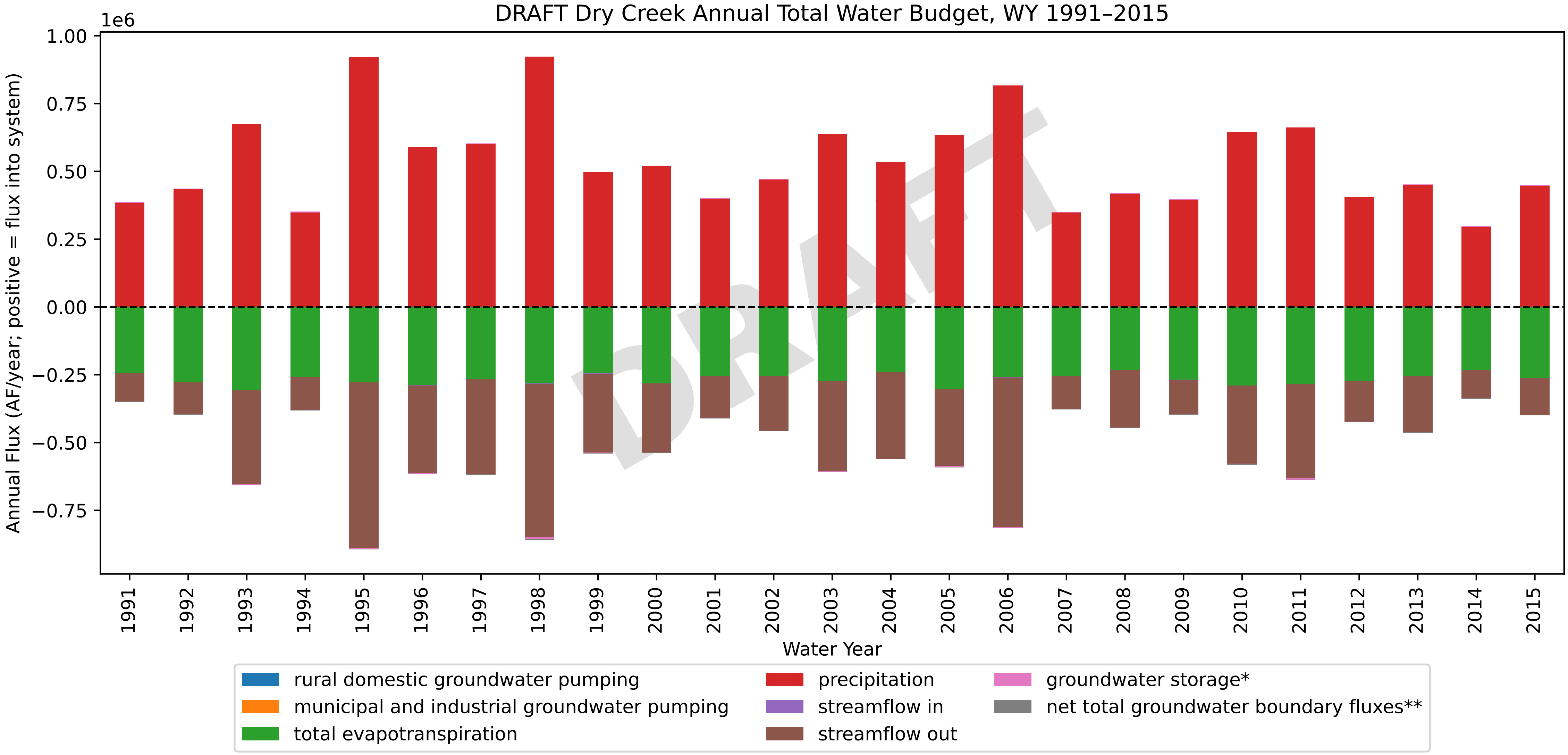

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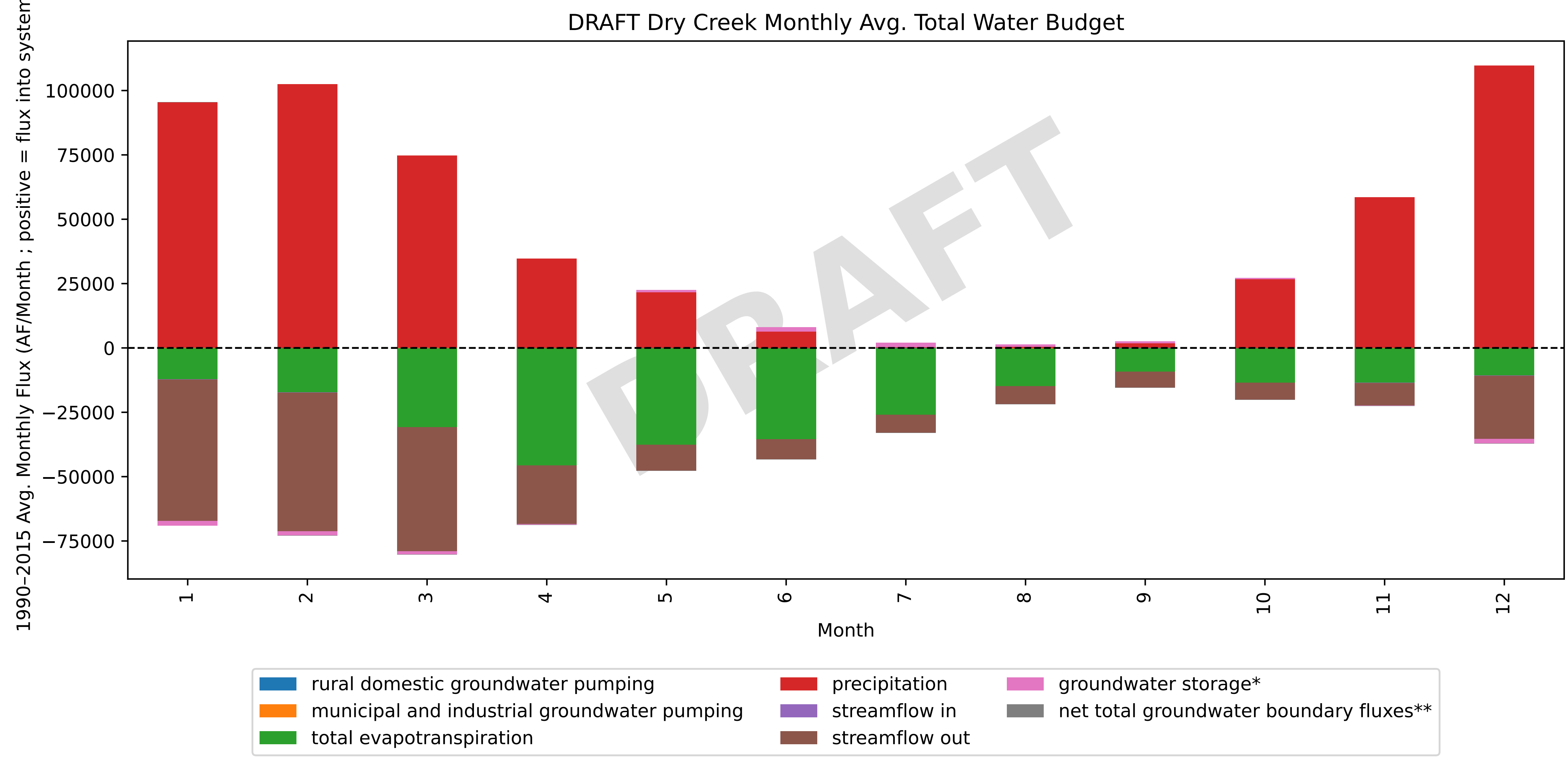

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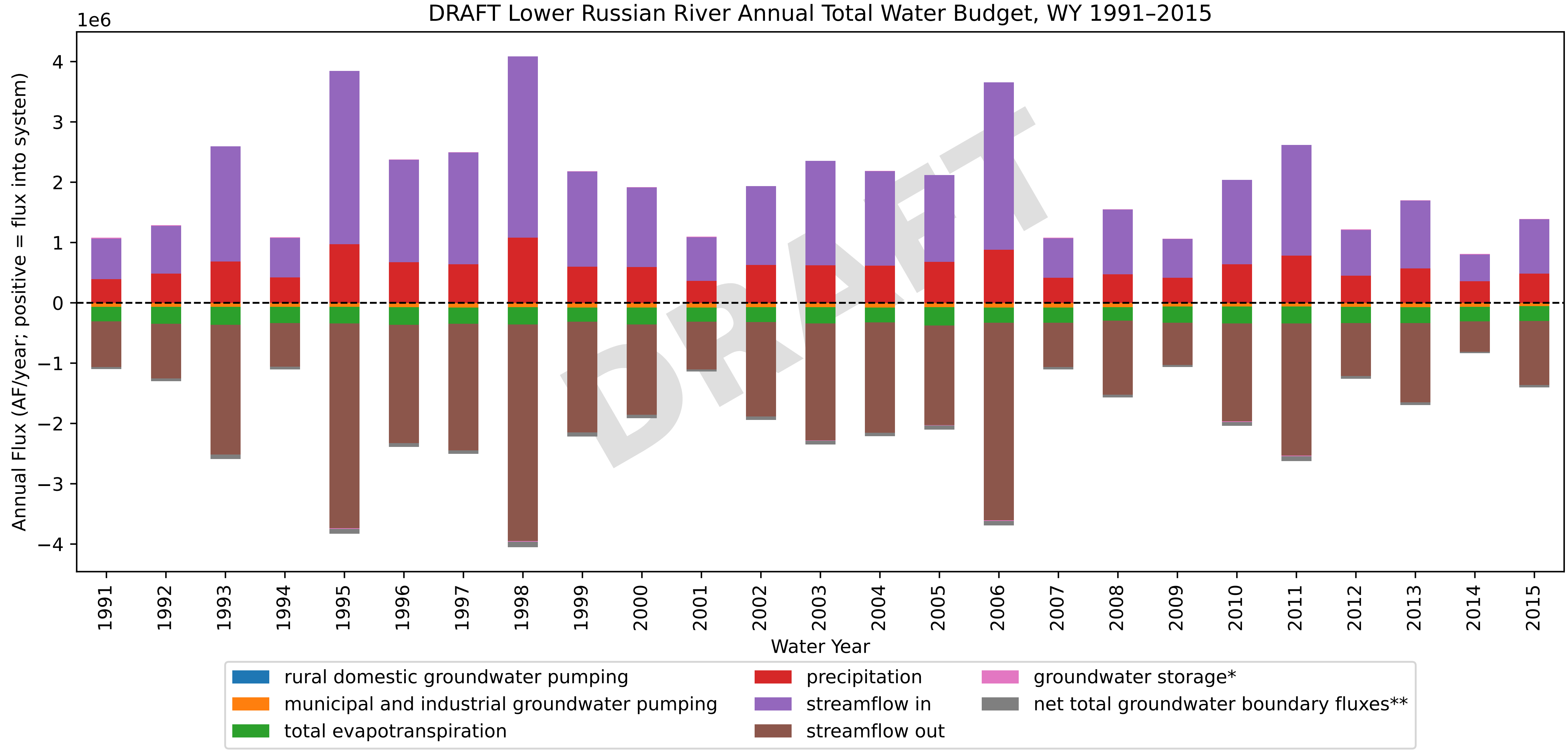
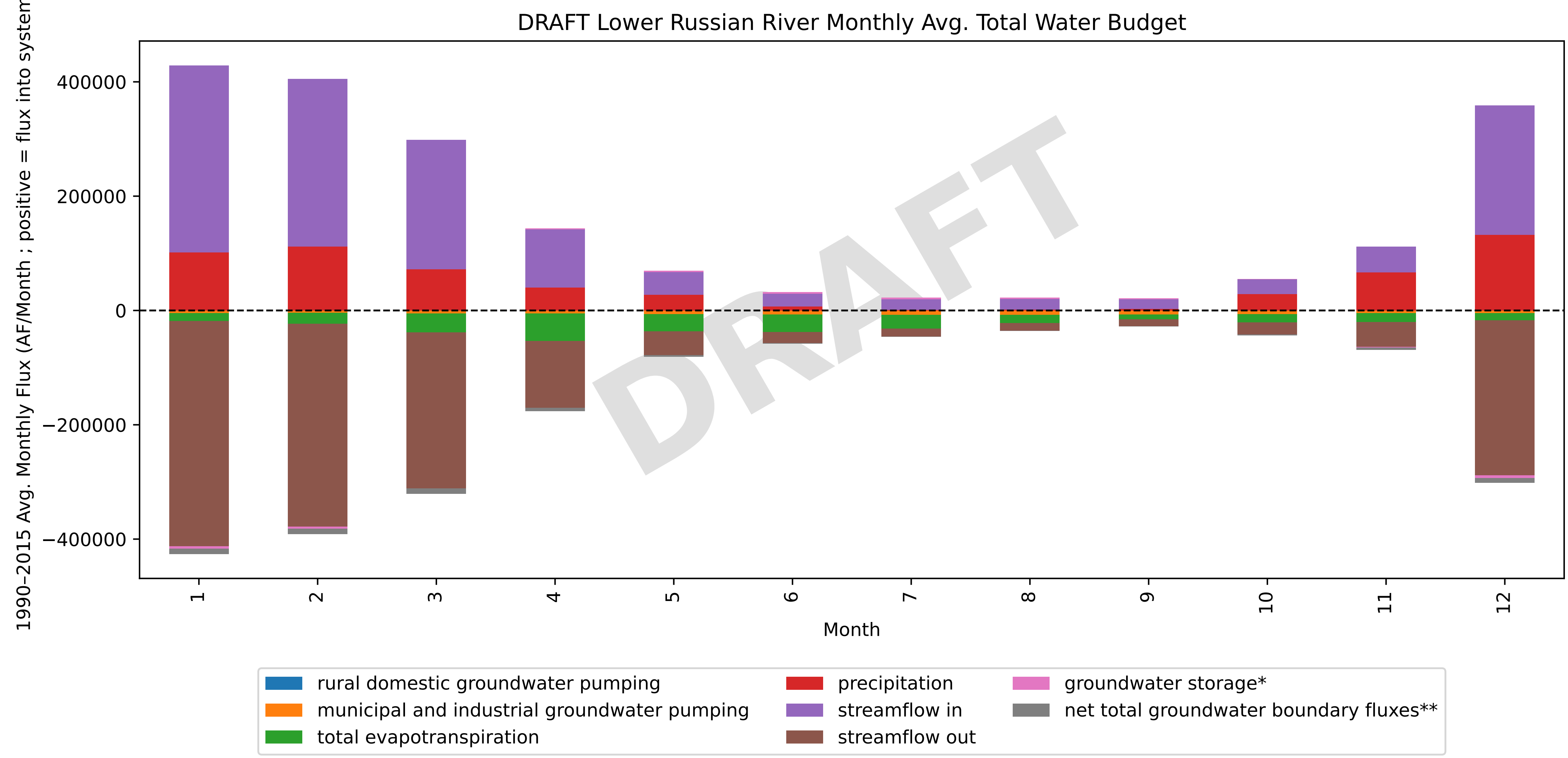

DRAFT Lower Russian River Annual Total Water Budget, WY 1991–2015

*Note: Positive storage values indicate the volume of groundwater that is released from storage. Negative storage values indicate the volume of groundwater that is partitioned into storage.**Note: Total boundary groundwater fluxes comprise fluxes from other subbasins within the model domain, head dependent boundary fluxes, and constant head fluxes



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