FORMA PROJECT
Mathematatic optimization model of the water resources
Elqui basin, Chile

Internship report

CIE4040-9 Internship

STUDENT:

Felipe Garcia Grez | 5449138

SUPERVISORS:

Dr. Ir. Edo Abraham | TU Delft
Corine ten Velden | Deltares
Marta Faneca | Deltares

November 2022

Table of Contents

Figures Index

Tables Index

Appendix Index

1. Project description

1.1. Context

Chile is well known for being a long and narrow country, trapped between the Pacific Ocean and the Andes mountain range. Because of this atypical shape and location, you can also find all types of climates across the country, and this is our special interest for the region of Coquimbo, located on the edge of the division line between the semi-arid climate to the south and the desertic climate to the north.

Coquimbo region is then placed in this highly sensible location, and due to climate change and a long and continuous drought over the last 10 years, enormous pressure has been put on the scarce water resources available, with no sufficient water in the surface resources and a continuous depletion of the aquifers.

This situation led to a joint venture, in which the government of Chile and the government of The Netherlands worked together on the "Giragua" project (a first-stage project), where the infiltration capacities of both Elqui Bajo and Pan de Azúcar aquifers were studied and evaluated, with enormous knowledge generation within the basins. A general view of the study area is shown in Figure 1.

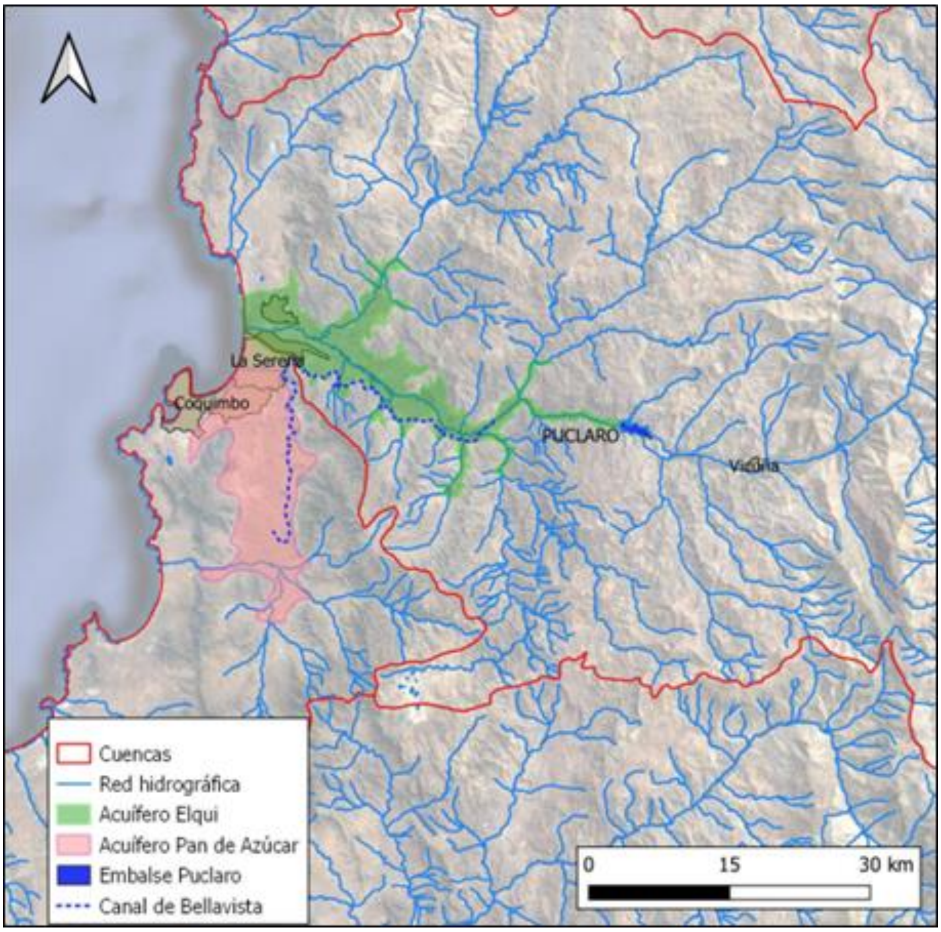


Figure 1: Study area
Source: GIRAGUA report (Oct. 2022)

1.2. Project objectives

The previous project of "Giragua" set down the foundations of the research project of FORMA (Exploring the use of real-time and Forecast data to Optimize Reservoir and aquifer Management).

The main objective of the project was in the first place to assess the possibility of making joint use of the reservoir and aquifer and evaluate the gain of this technique for the historical 10 – year period of 2010 – 2019. This period was very characteristic of the region, corresponding to low precipitation years and between them a high precipitation period (2016 – 2017 in this case).

If the gain of joint use of both aquifer and reservoir is positive and can be quantified, then this optimization methodology can be adjusted in the future to be used by the decision-makers of the basin for improving the water availability and preventing the depletion of both Elqui and Pan de Azúcar aquifers using real-time data.

2. Development of the project

2.1. Team involved

The FORMA project was in a "stand by" status before this internship since there were no people actively working on it. This meant that the start was almost from scratch based on an existing basic model. The project is being carried out from three different departments that share ideas and knowledge from different expertise: the Groundwater Management department (GWB) from the Subsurface & Ground-water Systems unit, the Catchment & Urban Hydrology department (HYD), and the Operational Water Management & Early Warning department (OWM), both from the Inland Water Systems unit. The team includes:

- Marta Faneca (GWB)
- Corine ten Velden (HYD)
- Bernhard Becker (OWM)
- Teresa Piovesan (OWM)
- Felipe García (HYD – Intern)

This way, once the project started moving again, many people were interested in following the steps of this internship.

2.2. Conceptual model

To schematize the model in the simplest possible way, but assuring that all relevant factors are still being included in the model, the FORMA project conceptual model shown in Figure 2 was used. This conceptual model is key for understanding:

- the water resources routing considered in the model. This means the location of the different demands along the river and the aquifer location.
- the sources of data for each one of its components. Where are the water demands defined, the aquifers recharge and extractions, etc.
- the goals stated. What is this research pursuing? Which are the values that this research is trying to maximize or minimize?

- the boundary conditions used (aquifers infiltration capacity, Canal Bellavista discharge capacity, etc.)

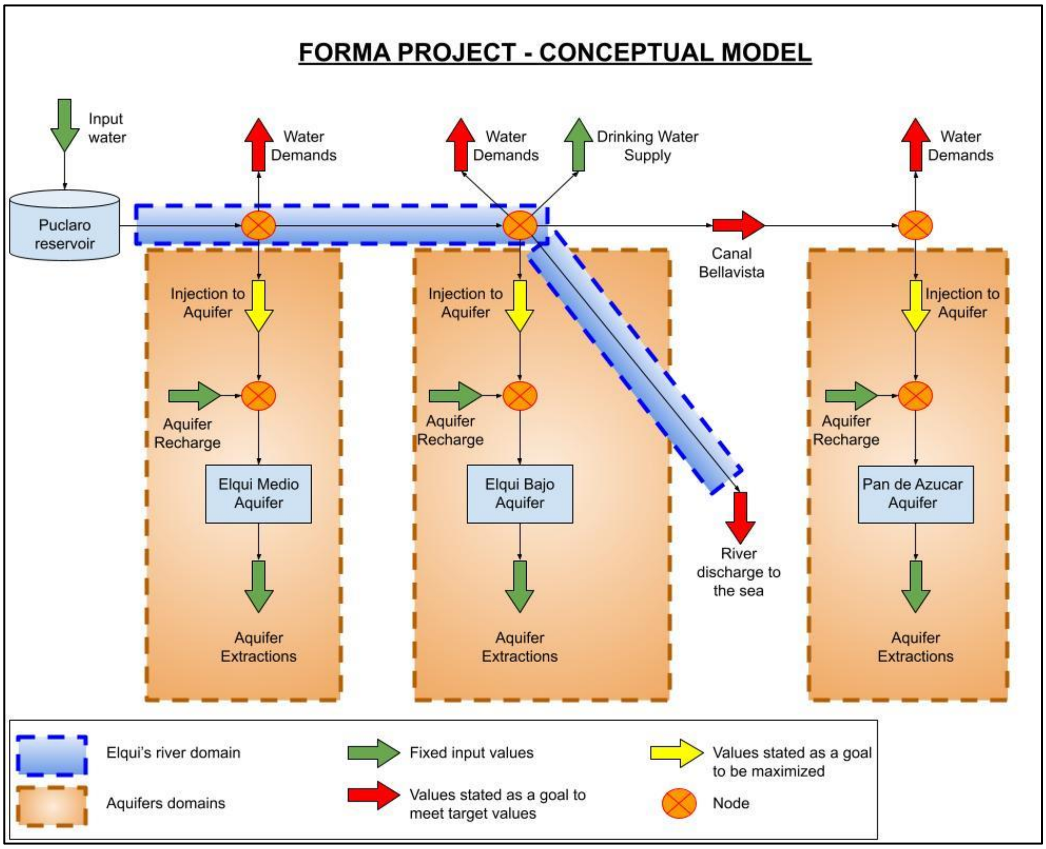


Figure 2: Conceptual model of the FORMA project
Source: Own elaboration

2.3. Software involved

2.3.1. OpenModelica

The model developed during the internship was built using two open-source software packages, as is the policy at Deltares. The "OpenModelica Connection Editor" and "RTC-Tools", are both based on the Python script, being easy to import and export data from one to another since both have the same language.

OpenModelica[1] is used for the schematization of the model, where all connections and boundary conditions are defined. It is simple to use and due to the graphical interface used it is easy to spot over any mistakes on the routing. OpenModelica translates the graphic schematization defined by the user to a writeable version of it so it can be easily exported and used for other software, like RTC-Tools. In Figure 3 it is shown what the model looks like in the OpenModelica software, which was created based on the conceptual model previously shown.

[1] https://openmodelica.org/

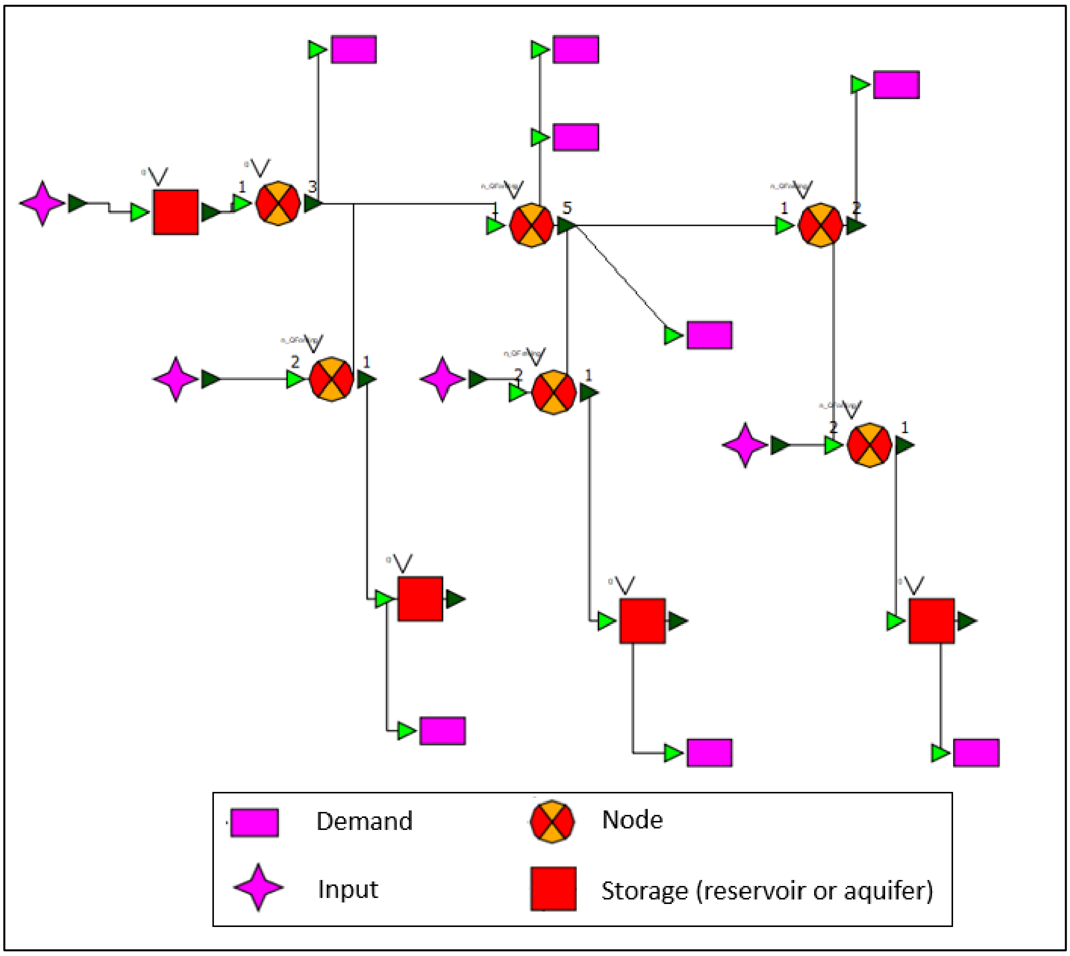


Figure 3: OpenModelica schematization
Source: Screenshoot from OpenModelica file

2.3.2. RTC-Tools

The RTC-Tools[2] software, as its name says, is a real-time control tool used to support operational decisions in any time scale (weeks, months, and even years) by means of finding the optimal operational scheme. This optimal scheme means that given some specific input or fixed values, the software seeks for the best possible outcome given the objectives that have been defined. In this specific project, the RTC-Tools models looks for the best operation of the reservoir in order to satisfy the water demands, the environmental restrictions and the aquifers infiltration, given the physical restriction of the system (discharge capacity of the canals, infiltration capacity, reservoir volume, etc.) This software is used to support operational decisions and also to explore new ways of management.

RTC-Tools works through multi-objective optimization, iterating for the optimal value of the function, from the higher priority goal to the lower priority goal. The goal violation hardness can also be defined by giving a “high order” to the goal, meaning that the goal violation value is taken to the order’th power in the objective function.

[2] https://www.deltares.nl/en/software/rtc-tools/

The optimization process can include the so-called “path goals”, where there is an objective for the specific function in every timestep of the simulation. In the same way, it is also possible to set goals for only one specific timestep (i.e. the last timestep) for any function of interest, making the software very flexible to adapt to any needed circumstances.

2.4. Sources of data

The data collection for building the RTC-Tools optimization model proved to be one of the most challenging parts of the internship, depending on third parties and also old models with no apparent owner. The different inputs needed, detailed in Figure 2, were obtained from different sources that are summarized in Table 1.

Table 1: Input data sources for the RTC-Tools model

Input data required[3]	Source	Source (detail)
Input water or Inflow to Puclaro reservoir	DGA	Statistics DGA station, online information[4]
Water demands	Universidad de La Serena (ULS)	WEAP model results
Drinking water supply		
River discharge to the sea or minimum ecological flow	PEGH[5], DGA.	PEGH report
Aquifer recharge	Giragua project, Deltares	iMOD model results
Aquifer extractions		

2.4.1. Statistics DGA monitoring station

The inflow into Puclaro reservoir was supposed to be taken from the latest version of the WEAP model, but this information didn’t arrive. To carry on, the available data from the DGA fluviometric stations were used for the 10–year period of interest (2010 – 2019), where the original data is presented as the average monthly discharge in m3/s. The station used corresponds to the “*Río Elqui en Algarrobal*” station, located almost 23 km upstream of the Puclaro reservoir. The detail of this data is shown in Appendix A, and the discharge plot is shown in Figure 4.

[3] Using the same denomination as in Figure 2.
[4] https://dga.mop.gob.cl/servicioshidrometeorologicos/Paginas/default.aspx
[5] “Plan Estratégico de Gestión Hídrica en la Cuenca de Elqui” (Nov–2020), realized by UTP Hídrica -ERIDANUS for Dirección General de Aguas (DGA-MOP Chile).

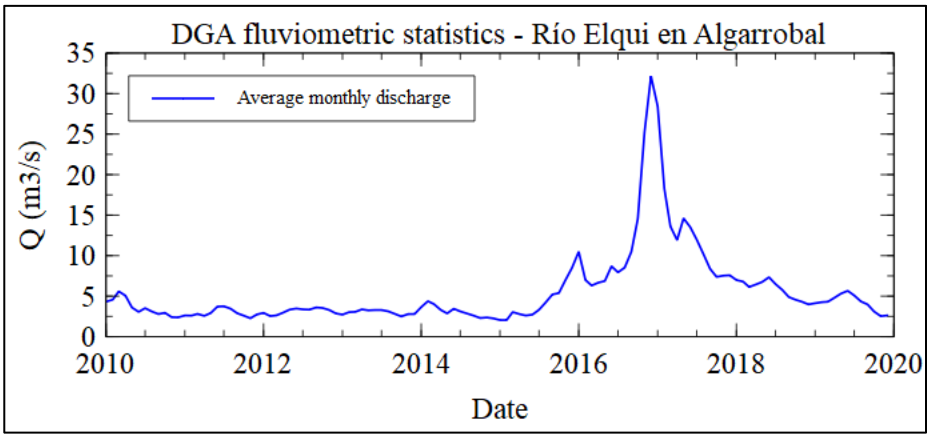


Figure 4: Average monthly discharge from DGA's fluviometric station
Source: Own elaboration

2.4.2. WEAP model results

Water demands for irrigation and for drinking water supply were taken from an existing WEAP model developed during the PEGH elaboration. Because no WEAP license is available at Deltares nor TU Delft University, the original WEAP model wasn't the direct source of the information and Universidad de La Serena shared with Deltares the excel files that contain all demand data of the WEAP model. These demands correspond to the target value for the optimization, meaning that the RTC-Tools model will try to satisfy them as much as possible given the other demands and constrains.

In order to facilitate the management of data in this project, the different demands were aggregated considering their location, regarding the WEAP schematization shown in Figure 5, corresponding to the area downstream of the Puclaro reservoir.

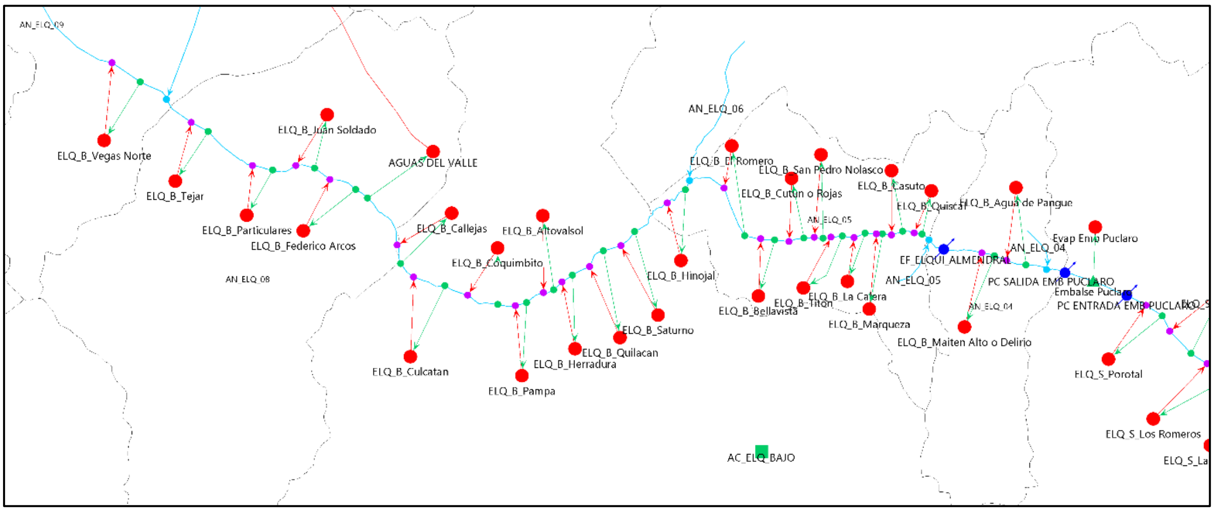


Figure 5: WEAP demands schematization for part of the Elqui river downstream of the Puclaro reservoir
Source: Universidad de la Serena

These demands can be summarized as it is in Table 2:

Table 2: Summary of WEAP model demands considered in the FORMA project

Location	Location_ID	Demand_ID
Elqui Medio	Q_demands1_target	ELQ_B_Agua de Pangue
		ELQ_B_Maiten Alto o Delirio
		ELQ_B_Quiscal
		ELQ_B_Casuto
		ELQ_B_Marqueza
		ELQ_B_La Calera
		ELQ_B_Titon
		ELQ_B_San Pedro Nolasco
		ELQ_B_Cutun o Rojas
		ELQ_B_El Romero
		ELQ_B_Hinojal
		ELQ_B_Saturno
		ELQ_B_Quilacan
		ELQ_B_Herradura
		ELQ_B_Altovalsol
		ELQ_B_Pampa
		ELQ_B_Coquimbito
Elqui Bajo	Q_demands2_target	ELQ_B_Culcatan
		ELQ_B_Callejas
		ELQ_B_Federico Arcos
		ELQ_B_Juan Soldado
		ELQ_B_Particulares
		ELQ_B_Tejar
		ELQ_B_Vegas Norte
Aguas del Valle	Q_demandsADV_target	AGUAS DEL VALLE
Pan de Azúcar	Q_demands3_target	ELQ_B_Bellavista

Figure 6 shows the target demands of the different locations. The detailed information on the WEAP model demands is presented in Appendix B.

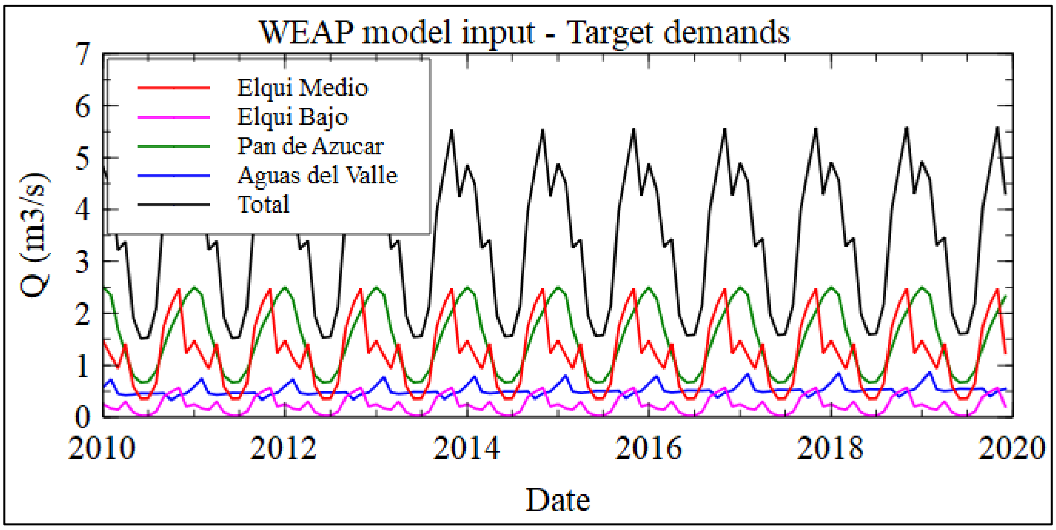


Figure 6: WEAP model input - Target demands
Source: Own elaboration

2.4.3. PEGH report

The river discharge to the sea was set as a goal to be met due to environmental conditions that need to be considered. The only available information regarding this topic is stated in the PEGH report under the topic of "reserved discharges for environmental protection", where monthly values are stated according to Table 3.2-2 of the PEGH report (see Figure 7). This information is the only available data regarding environmental restrictions on the river, but do not correspond directly to the minimum ecological flow we are looking for. Because of this, the following assumption has been made: the minimum ecological flow corresponds to the 20% of the environmental protection discharge. This is presented in Figure 8.

Tabla 3.2-2 Caudal de reserva para protección ambiental (m^3/s) en "Río Elqui en La Serena"

ENE	FEB	MAR	ABR	MAY	JUN	JUL	AGO	SEP	OCT	NOV	DIC	ANUAL
4,93	4,48	3,36	4,49	5,32	5,84	9,16	5,77	4,08	2,88	4,34	3,84	7,24

Fuente: Elaboración propia en base a DGA (2020a).

Figure 7: Reserve river discharges for environment protection.
Source: PEGH report

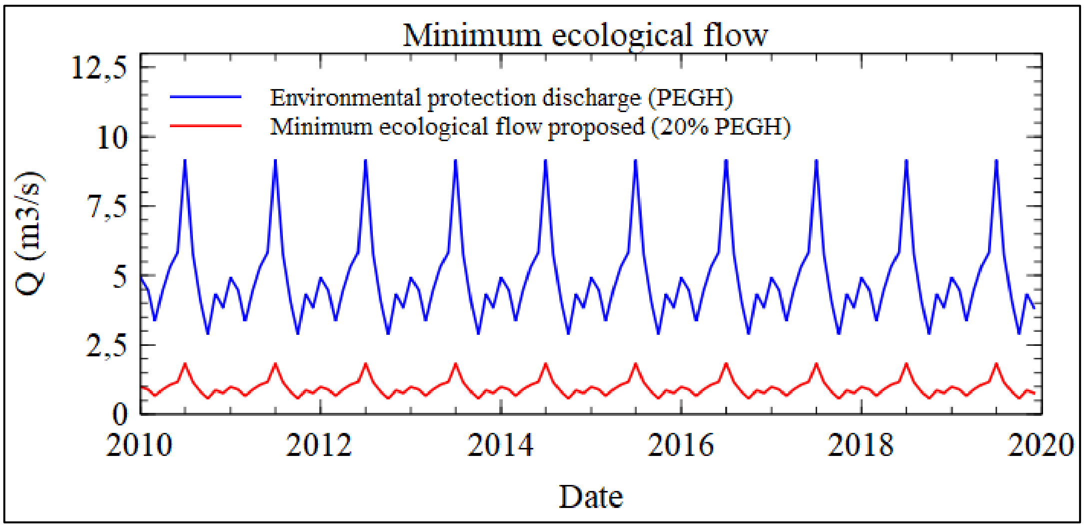


Figure 8: Minimum ecological flow
Source: Own elaboration

2.4.4. iMOD model results

During the realization of the Giragua project, a groundwater model was created, in order to evaluate the current conditions of the aquifers and integrating all the geophysical data collected during the terrain campaigns. In accordance with the observations and the available surface water models, Deltares developed two groundwater models based on the iMOD[6] software, simulating the current

[6] https://www.deltares.nl/nl/software/imod-2/

conditions of both the Elqui and Pan de Azúcar aquifers. The Elqui aquifer model comprehends the area downstream of the Puclaro reservoir until the sea.

The iMOD model results are extracted in a text format file, in which all the inflow and outflow rates, for each monthly timestep, are given for each model package (components) included (WEL_SYS, RIV_SYS, RCH_SYS, GHB_SYS, etc.), corresponding to the well interactions, river interactions, recharge interaction and boundary condition interactions.

For the RTC-Tools model, the specific data used for the aquifers recharge and the aquifers' extractions are detailed in Table 3.

Table 3: iMOD model data used

Aquifer	Parameter	Packages used	Comments
Elqui	(A) Lateral recharge/discharge	WEL_SYS2, WEL_SYS3, WEL_SYS4, WEL_SYS5, WEL_SYS6	Boundary conditions
	(B) River recharge	RIV_SYS1	River – aquifer interaction
	(C) Natural recharge/discharge	RCH_SYS1, RCH_SYS2, RCH_SYS3, RCH_SYS4	Precipitation, Irrigation, losses in canals with info, losses in canals without info
	(D) Drainage	DRN_SYS1	-
	Total recharge/discharge	-	(A) + (B) + (C) + (D)
	Aquifer extractions	WEL_SYS7, WEL_SYS8, WEL_SYS9	Well extractions
Pan de Azúcar	(A) Lateral recharge/discharge	GHB_SYS1, GHB_SYS2, GHB_SYS3, GHB_SYS4	Boundary conditions
	(B) Natural recharge	RCH_SYS1, RCH_SYS2, RCH_SYS3, RCH_SYS4	Precipitation, Irrigation, Losses in canals with info, Losses in canals without info
	(C) Sea intrusion	CHD_SYS1	Aquifer – sea interaction
	(D) Drainage	DRN_SYS1	-
	Total recharge/discharge	-	(A) + (B) + (C) + (D)
	Aquifer extractions	WEL_SYS3	Well extractions

The values computed for the Elqui aquifer have been distributed in equal parts for the Elqui Medio and Elqui Bajo aquifers modeled in RTC-Tools.

The output text files from de iMOD models are presented in Appendix C.

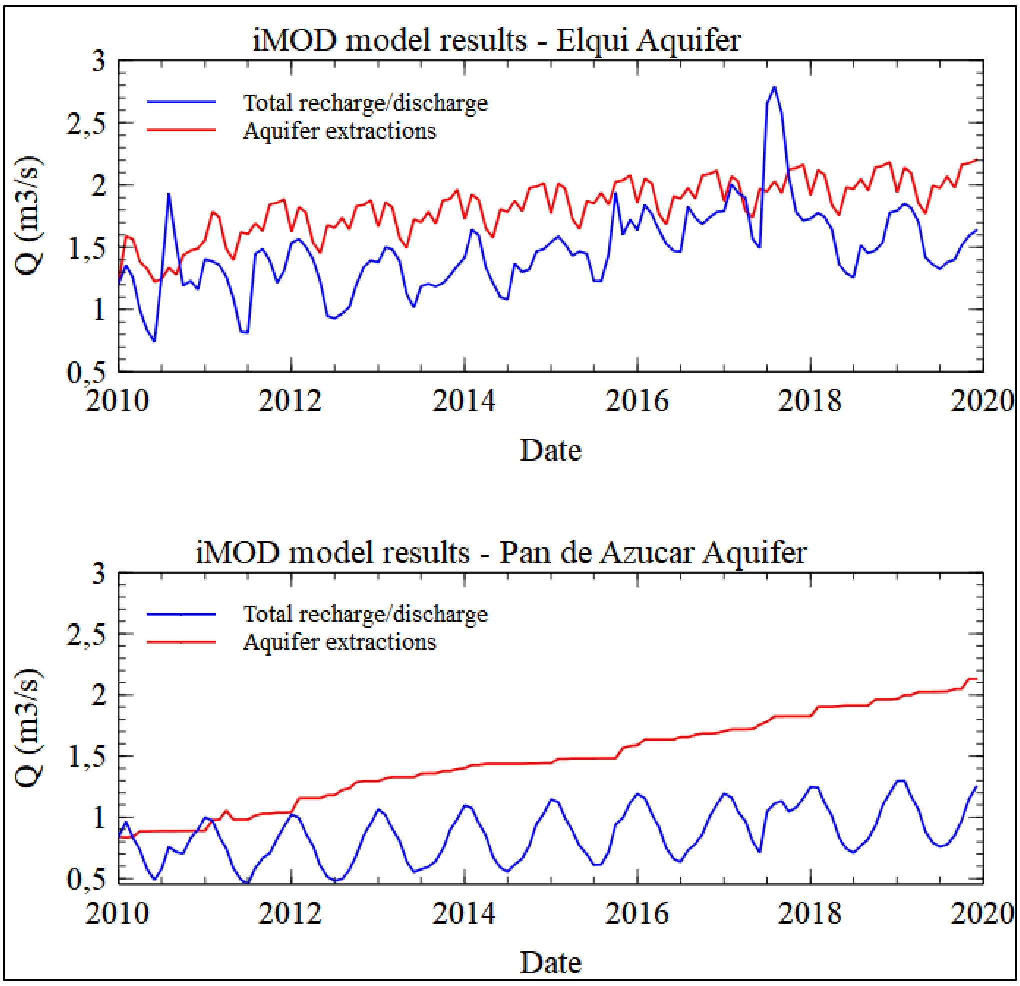


Figure 9: Data extracted from the iMOD models
Source: Own elaboration

2.5. Potential Irrigation demands (PID) vs "*Desmarque*"

Is important to clearly distinguish between the concepts of potential irrigation (PID) demand and desmarque, since both refer to a discharge value, but they are used from different perspectives.

The total potential irrigation demands refer to the irrigation needed to water the existing/expected crops. It is computed in terms of the demand and not the water availability of the river. The WEAP model results detailed in section 2.4.2 correspond to this total potential demand.

The "desmarque" corresponds to a percentage of the water shares or "*acciones*" that are available on the river and can be effectively used by the users for irrigation. This water allocation system has a long-using tradition and is administrated by a local authority called *"Junta de vigilancia"*. This authority is who define the value of the "desmarque" each year by assessing a number of variables (storage volume, snow depth in the higher part of the catchment, runoff correlations, etc.) defining this way how much water the shareholders (users) will have. These users normally correspond to farmers, but can also be water companies and other industries.

The Elqui river, downstream of the Puclaro reservoir ("*3ra sección*"), have 11,990 water shares ("*acciones netas*"), corresponding to 11.99 m3/s[7]. Table 4 shows how the PID from WEAP is related to the "desmarque".

Table 4: Potential irrigation demand vs Desmarque

PID fraction (-)	Desmarque (%)	Peak discharge value (m3/s)	Comments
0.83	35.0%	4.20	Minimum desmarque proposed[8]
1.00	42.4%	5.08	WEAP model values
1.12	47.5%	5.70	Average desmarque[9]
1.65	70.0%	8.39	Historical maximum desmarque[9]

2.6. Goals description

For any optimization model, the optimal result depends of course on the goals stated but also on the priority given to these goals. A brief description of the stated goals is included below:

- Irrigation demands: This goal's objective is that the irrigation demands can be satisfied as much as possible since it represents the most important economic income of the area. The expected irrigation demand to be satisfied corresponds to the surface water resources on Elqui Medio (Q_demands1_target), Elqui Bajo (Q_demands2_target), and Pan de Azúcar (Q_demands3_target).

- Drinking water supply demands: The drinking water supply requirements need to be satisfied since access to water for living is a human right. In this project, the water supply corresponds to the "*Aguas del Valle*" demand (Q_demandsADV_target). *"Aguas del Valle"* corresponds to the drinking water company present in the area which is responsible for the drinking water supply of big cities like La Serena and Coquimbo, and also all the smaller drinking water consumers.

- Minimum ecological flow: Environmental restrictions play an important role in any water allocation problem, and so, the minimum ecological flows (Q_ecoMinflow) need to be met at the end of the water course to maintain the living conditions along the river.

- Aquifer artificial infiltration: Because of the continued decrease of the water levels in both aquifers, the main objective of the Giragua and FORMA projects has been always to achieve an effective aquifer infiltration, trying to maximize the artificial infiltration value.

- Avoid Puclaro depletion: This goal needs to be implemented to constrain the use of water at the end of a simulation, because if it is not set, the optimization uses all water in the reservoir,

[7] Each water share ("*accion neta*") corresponds to 1 l/s.
[8] This minimum value was established in the Giragua project report as the minimum the farmers need. See Appendix D.
[9] Corresponds to the 30–year period modeled (Sep–19 to Sep–49) in accordance with FIA (2020). See Appendix D.

emptying the Puclaro reservoir. The goal corresponds to reaching the starting volume of the reservoir on the last timestep.

- Puclaro operational rules – Minimum volume: As is detailed in the operational manual of the Puclaro reservoir, one of the many rules states that the minimum volume at the end of each irrigation season, in August, must be at least 20 million cubic meters. The irrigation season starts in September and ending in August.

- Fairness on the aquifer artificial recharge: This goal has been implemented so that the ratio of the volume change (volume in the first timestep divided by the volume in the last timestep) of the Elqui aquifer is as close as possible to the ratio of change of the Pan de Azúcar aquifer. With this, the aquifer infiltration can be assigned to the aquifer that has lost the most volume during the simulation.

- Minimize rate of change on aquifer infiltration: The objective of this goal is to have a smooth result on the infiltration scheme. If not stated, the behavior of the infiltration is erratic and full of peaks, making it impossible to translate it into a feasible and reproducible operation in real life.

2.7. Boundaries

There are some physical restrictions that need to be considered in the model for a more realistic approach. These hard constraints are forced to be satisfied under any circumstances, corresponding to:

- Maximum capacity of infiltration in the aquifer: The installed capacity for artificial recharge to the aquifer is limited by the number of infiltration wells or the extent of the infiltration basins that are considered. Another consideration for this is the estimated available water that would be offered by users for infiltration.

  Based on the GIRAGUA report (October 2022), different infiltration scenarios were analyzed due to this consideration, and those are included in the present report as a “Reference case”. The boundary conditions are presented in Table 5.

Table 5: Infiltration boundary conditions

Aquifer	Giragua's scenario considered	Maximum infiltration capacity (m3/s)
Elqui	Scenario B: considers 2 recharge basins on both sides of the Elqui's river with an infiltration capacity of 1 m/day. This capacity led to a max infiltration discharge of 900 l/s. (section 2.2.5 of Giragua report, see Appendix D)	0,90[10]
Pan de Azúcar	Scenarios B and E: considers the maximum amount of available water in Canal Bellavista due to the difference between the minimum and average "*desmarque*" for the last 30 years. (section 2.1.3 of Giragua report, see Appendix D)	0,92

- Maximum capacity of "Canal Bellavista": This canal has a limited capacity that needs to be shared between the agricultural demand and the artificial recharge in the Pan de Azúcar sector. So, in practice, the irrigation demand goal and the infiltration in the Pan de Azúcar aquifer are competing for the use of the canal capacity. The actual discharge capacity of this canal, based on the total net "*acciones*", corresponds to 3.667 m3/s. (section 2.1.3 of Giragua report, see Appendix D).

2.8. Executable files

2.8.1. Input data generator code

Because of the multiple sources of information and the need to constantly change the input parameters for the RTC-Tools model, a Python script was elaborated so the CSV input files required by RTC-Tools are created automatically.

The first thing done by the code is to state the initial state conditions of the model (reservoir and aquifer's initial volume, and reservoir initial discharge release). The initial values used are stated in Table 6.

Table 6: Initial state conditions

Description	Initial value
Puclaro Initial volume (x 10^6 m3)	50
Puclaro Initial release (m3/s)	5
Elqui Medio aquifer Initial volume (x 10^6 m3)	400
Elqui Bajo aquifer Initial volume (x 10^6 m3)	400
Pan de Azúcar aquifer Initial volume (x 10^6 m3)	400

After that, the code goes through all the different sources of data already described, and nicely organizes them all in the format required by RTC-Tools. In this part of the script there is the possibility

[10] This maximum infiltration capacity will be equally divided between Elqui Medio and Elqui Bajo aquifer since these corresponds to the same aquifer.

to quickly change some parameters to analyze different scenarios and sensitivity of the model, such as:

- Fraction of the PID: corresponds to the fraction of the irrigation demand taken from the WEAP model to be considered.
- Percentage of minimum ecological flow: As was indicated in section 2.4.3, 20% of the environmental protection reserved discharge was considered as the minimum ecological flow, but this can easily be changed here.
- Canal Bellavista maximum discharge: This boundary condition can also quickly be changed here.
- Maximum infiltration rate: The boundary condition of each aquifer also can be modified here to analyze the effect of having less or more infiltration capacity for any of them.

The details of this executable code are presented in Appendix E.

2.8.2. FORMA RTC code

The RTC-Tools script has a specific structure that must be followed in any project for this is how the software package is built. On any RTC projects one of the most important parts is the construction and definition of the "Goal Classes". Each goal (that we want to be achieved) must be define as a single class, specifying which value or mathematical function we are optimizing, and if this value or function should be maximized, minimized or have to be close to a specific value. Later on we can use each "Goal Class" multiple times to define goals (in a specific timestep) or path goals (to be achieved in every timestep) with the corresponding prioritization.

In general, any RTC-Tools Python script project should have the following order:

- Definition of the "Goals Classes"
- Class FORMA
    - Definition of method pre: previous calculation to be used after or to store intermediate results
    - Definition of method bounds: store the boundaries included in the model
    - Definition of method path-goals / goals: store the different goals to compute
    - Definition of method goal_programming_options: setting of the optimization
    - Definition of method post: posterior analysis of the data or to show results
- Run FORMA

In this specific project, 11 "Goal Classes", 4 boundary conditions, 6 path goals, 2 goals, and 2 programming options were defined. All of this is summarized in Table 7.

Table 7: FORMA RTC code structure

Section	Class / Method	Method
“Goal Classes” definition	IrrigationDemandsGoal	-
	WaterSupplyDemandGoal	-
	MinEcoFLow	-
	MinMonthlyVolRes	-
	MaximizeAquiferInfiltration	-
	PuclaroDeplitionGoal	-
	FairRechargue	-
	MinimizeRateChangeInfiltrating	-
Class FORMA	pre	-
	bounds	Demands boundary
		Aquifer infiltration boundaries
		River discharge boundaries
		Canal Bellavista boundaries
	Path goals	Each goal class is included in the goals with their respective priority
	Goals	Each goal class is included in the goals with their respective priority
	Goal_programing_options	“keep_soft_constrains” is set
		“contraint_relaxation “is set
	post	Results extraction
Run FORMA	-	-

The FORMA RTC Python script used in this project is shown in Appendix F.

3. Goals prioritization

The prioritization has been fixed considering the real criteria that drive the water allocation in the basin, as shown in Table 8.

Priority 1 is stated in the constitution of the country, therefore having drinking water for human consumption is prioritized over any other use. Environmental restrictions are also stated in law, so this is included as a second priority.

The 3rd priority is taken from the “Operational Rules Manual”[11] of the Puclaro reservoir. This gives a high priority to the fulfillment of the minimum volume at the end of each irrigation season.

Taking into account that these priorities are fixed due to laws and policies, the only switch between goal priorities that was investigated is that between the irrigation demands vs the aquifer artificial infiltration. Since this change on priority is not likely to happen due the legal sustenance of the farmers on their own use of water (water rights), is a safe assumption that these goals’ order is not going to change on time.

---

[11] “Manual de Operaciones, Regla operacional”, Junta de Vigilancia del Río Elqui y sus afluentes, Dic-2019

Table 8: Prioritization of goals

Priority N°	Goal	Order[12]
1	Drinking water supply demands	1
2	Minimum ecological flow	1
3	Puclaro operational rules – Minimum volume	1
4	Avoid Puclaro depletion	1
5	Irrigation demands	1
6	Minimize rate of change on aquifer infiltration	1
7	Aquifer artificial infiltration	1
8	Fairness on the aquifer artificial recharge	1

4. Reference case and sensitivity analysis

4.1. Reference case and parameter sensitivity analysis definition

In order to have a proper definition of scenarios, the first step is to establish a “Reference case” in terms of the input values to be used and then run a sensitivity analysis through all these different inputs. This sensitivity analysis is a key step for recognizing the most relevant variables for the model, so that later different scenarios can be defined considering these results.

For the sensitivity analysis, the “Reference case” corresponds to the situation that is closest to the reality of the basin, considering the boundary conditions already defined in section 2.7. A “Low range” value and “High range” value for each input are used to test the results variation of the model using these single values that represents the minimum and maximum values for each parameter. The reference input, low and high range values are shown in Table 9, and the description/motivation of each value is presented in Table 10.

Table 9: Input values for sensibility analysis

Input N°	Input	Ref. input	Low range	High range
1	PID fraction (-)	1.00	0.83	1.65
2	Min_EcoFlow fraction (-)	0.20	0.10	1.00
3	Q_max of Canal Bellavista (m3/s)	3.67	1.00	4.95
4	Q_max_inf. Elqui Medio (m3/s)	0.45	0.10	10.00
5	Q_max_inf. Elqui Bajo (m3/s)	0.45	0.10	10.00
6	Q_max_inf. Pan de Azúcar (m3/s)	0.92	0.46	3.67

[12] Detail of this parameter is given in section 2.3.2 RTC-Tools.

Table 10: Description for input values used

Input N°	Description for the input value		
	Ref. input	**Low range**	**High range**
1	Total potential demand for irrigation	Minimum desmarque (35.0%)	Historical maximum desmarque (70%)
2	20 % of the Environmental Reserve	10 % of the Environmental Reserve	100% of the Environmental Reserve
3	Current capacity based in total number of "acciones"	-	Increase of 35 %
4	Scenario B of Giragua (0.90 m3/s)	Scenario A of Giragua (0.20 m3/s)	No restriction (10.00 m3/s x aquifer)
5			
6	Giragua max infiltration discharge (0.92 m3/s)	Giragua average infiltration discharge (0.46 m3/s)	100 % of CB capacity (3.67 m3/s)

For analyzing each model simulation result, the parameters stated in Table 11 have been used. In the same table, the results for the reference case are shown. The detail of each parameter calculation is shown in Appendix G.

Table 11: Reference case parameters results

Model results	**Reference case**
GOAL Results	
Drinking water supply goal (%)	100.00%
Ecological minimum flow goal (%) (*)	195.82%
Irrigation demands goal (%) (*)	76.03%
AQUIFER Results	
Elqui Aquifer	
Change % Elqui aquifer	1.01%
% of months that volume increases	45.38%
IEAS index	1.24
IEAS index with infiltration (*)	0.99
Pan de Azúcar aquifer	
Change % Pan de Azúcar aquifer	-14.61%
% of months that volume increases	32.77%
IEAS index	1.70
IEAS index with infiltration (*)	1.14
Total aquifer	
Change % on aquifers	-4.20%
% of months that volume increases	41.18%
IEAS index	1.41
IEAS index with infiltration (*)	1.05
PUCLARO Results	
Timesteps that releases meet demands	58.33%

(*) Parameter used in the sensitivity analysis.

The “IEAS index” corresponds to an index for sustainable ground water exploitation. The acronym is in Spanish, meaning “*Índice de Extraccion de Aguas Subterraneas*”. The index is calculated as follows:

$$IEAS = \frac{Total\ aquifer\ extractions}{Total\ aquifer\ recharge}$$

Therefore, for an aquifer that has been exploited in a sustainable way, the IEAS index value should be below 1.

As can be seen from the results of the Reference Case, in the current situation both aquifers have an unsustainable exploitation when the artificial infiltration is not considered. And if the artificial infiltration is taken into account, the Pan de Azúcar aquifer is still being exploited in an unsustainable way while the Elqui aquifer is right at the limit of its sustainable extraction. The detail of the results of the Reference Case is shown in graphs in Appendix I.

4.2. Sensitivity analysis results

The sensitivity analysis was done with the “Low range” and “High range” values of Table 9, and the deviation over the reference case result, presented in Table 11, are showed in detail in Appendix H. The results of the sensitivity analysis led us to obvious conclusions and other ones that are not too obvious.

In the first place, it is possible to recognize that there is still some potential to improve the aquifers' situation since the ecological minimum flow goal is almost always over 100%, meaning that there is a “waste” of water into the sea.

Secondly, the effect of the discharge capacity of Canal Bellavista is critical for both the irrigation demands goal and the Pan de Azúcar IEAS index (both rely on the water transported by this canal), so a reduction of the discharge capacity has a negative effect on them. Furthermore, an increase in the discharge capacity, only, will not have a positive effect on the aquifer if this measure is not done together with an increase in the infiltration capacity of the aquifer (more infrastructure).

Finally, it is relevant to recognize that any change in the infiltration capacity of any aquifer has no effect on the irrigation demands goal (top-right graph of Appendix H), so these two (irrigation and infiltration) are not directly competing since the priority of the irrigation demand is over the priority of the aquifer infiltration.

5. Model results

Regarding the previous sensitivity analysis, three different scenarios were defined considering the interest in the specific input variation and the expected improvements in results, corresponding to:

Scenario A: This scenario corresponds to the best feasible conditions for infiltration in the Pan de Azúcar aquifer, since this is the most depleted aquifer.

Scenario B: This scenario corresponds to Scenario A, but improves, even more, the conditions for infiltrating in the Pan de Azúcar aquifer by increasing both the discharge capacity of Canal Bellavista and the infiltration capacity with 35%.

Scenario C: This scenario corresponds to Scenario B, but in addition also improving the infiltration capacity of the Elqui aquifer with three times the capacity stated in the reference case.

Scenario D: This scenario corresponds to Scenario C, but now considering the maximum historical "*desmarque*" of about 70%.

The input values for Scenarios A, B, C and D are detailed in Table 12, and their justification is presented in Table 13. The result of each scenario is presented in Table 14.

Table 12: Input values for reference case, scenarios A, B, C and D

Input	Ref. case	Scenario A	Scenario B	Scenario C	Scenario D
PID fraction (-)	1.00	1.12	1.12	1.12	1.65
Min_EcoFlow (%)	0.20	0.20	0.20	0.20	0.20
Q_max of Canal Bellavista (m3/s)	3.67	3.67	4.95	4.95	4.95
Q_max_inf. Elqui Medio (m3/s)	0.45	0.45	0.45	1.35	1.35
Q_max_inf. Elqui Bajo (m3/s)	0.45	0.45	0.45	1.35	1.35
Q_max_inf. Pan de Azúcar (m3/s)	0.92	3.67	4.95	4.95	4.95

Table 13: Reference case and scenarios's input justification

Input	Ref. case	Scenario A	Scenario B	Scenario C	Scenario D
PID fraction (-)	Total potential demand for irrigation	The average desmarque of 47.5 % is used	The average desmarque of 47.5 % is used	The average desmarque of 47.5 % is used	Historical maximum desmarque of 70%
Min_EcoFlow (%)	20 % of the Environmental Reserve	Same as Reference Case	Same as Reference Case	Same as Reference Case	Same as Reference Case
Q_max of Canal Bellavista (m3/s)	Current capacity based in total number of "acciones"	Same as Reference Case	The discharge capacity is increased with 35%	The discharge capacity is increased with 35%	The discharge capacity is increased with 35%
Q_max_inf. Elqui Medio (m3/s)	Scenario B of Giragua (0.90 m3/s)	Same as Reference Case	Same as Reference Case	Infiltration capacity increased 3 times	Infiltration capacity increased 3 times
Q_max_inf. Elqui Bajo (m3/s)					
Q_max_inf. Pan de Azúcar (m3/s)	Giragua max infiltration discharge (0.92 m3/s)	Infiltration capacity equals the discharge capacity of Canal Bellavista	Infiltration capacity equals the discharge capacity of Canal Bellavista	Infiltration capacity equals the discharge capacity of Canal Bellavista	Infiltration capacity equals the discharge capacity of Canal Bellavista

Table 14: Model results for the reference case and for scenarios A, B, C and D.

Model results					
Scenario	**Reference**	**A**	**B**	**C**	**D**
GOAL Results					
Drinking water supply goal (%)	100.00%	100.00%	100.00%	100.00%	100.00%
Ecological minimum flow goal (%)	195.82%	160.24%	139.74%	118.89%	119.15%
Irrigation demands goal (%)	76.03%	72.69%	72.69%	72.69%	63.03%
AQUIFER Results					
Elqui Aquifer					
Change % Elqui aquifer	1.01%	0.68%	1.26%	11.26%	-3.06%
% of months that volume increases	45.38%	46.22%	45.38%	38.66%	18.49%
IEAS index	1.24	1.24	1.24	1.24	1.24
IEAS index with infiltration	0.99	0.99	0.98	0.86	1.04
Pan de Azúcar aquifer					
Change % Pan de Azúcar aquifer	-14.61%	0.68%	15.27%	11.26%	13.01%
% of months that volume increases	32.77%	42.86%	36.97%	31.09%	22.69%
IEAS index	1.70	1.70	1.70	1.70	1.70
IEAS index with infiltration	1.14	0.99	0.88	0.91	1.13
Total aquifer					
Change % of aquifers	-4.20%	0.68%	5.93%	11.26%	6.37%
% of months that volume increases	41.18%	43.70%	41.18%	36.13%	21.01%
IEAS index	1.41	1.41	1.41	1.41	1.41
IEAS index with infiltration	1.05	0.99	0.94	0.88	1.08
PUCLARO Results					
Timesteps that releases meet demands	58.33%	55.83%	56.67%	55.00%	38.33%

The details of the results of Scenario A are shown in graphs in Appendix J.

The details of the results of Scenario B are shown in graphs in Appendix K.

The details of the results of Scenario C are shown in graphs in Appendix L.

The details of the results of Scenario D are shown in graphs in Appendix M.

In terms of the variation in discharges and volumes for both Elqui and Pan de Azúcar aquifers, the results are compared in Figure 10 and Figure 11.

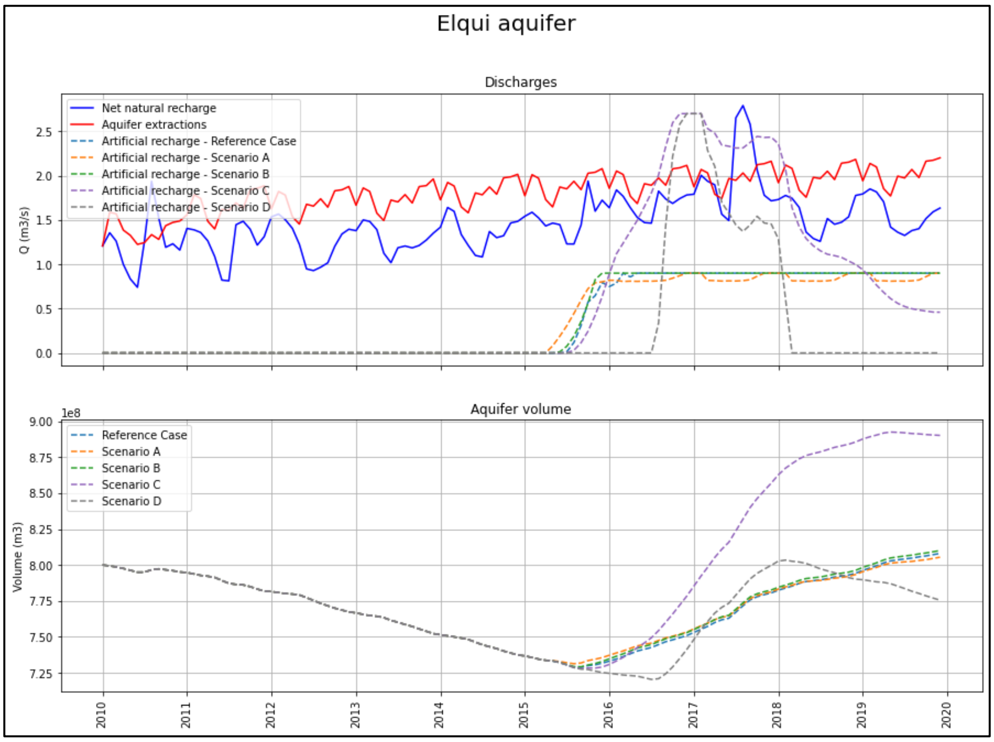


Figure 10: Elqui aquifer - Scenario comparison
Source: Own elaboration

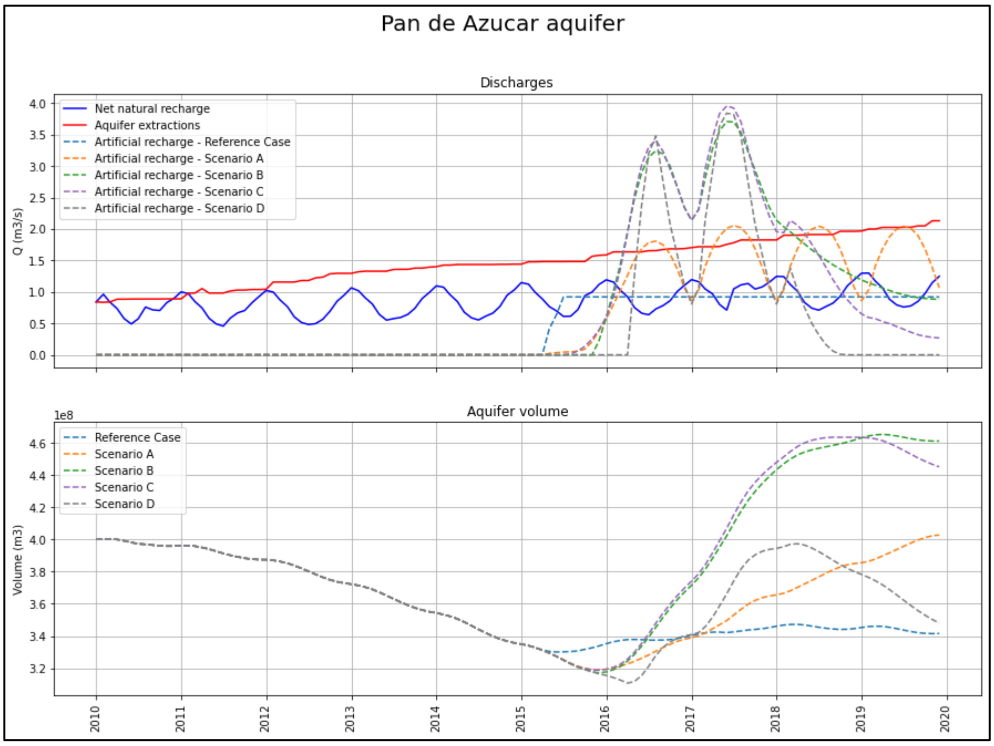


Figure 11: Pan de Azúcar aquifer - Scenario comparison
Source: Own elaboration

It's interesting to notice that the extreme inflow values registered at the entrance of Puclaro reservoir correspond to the irrigation season of year 16-17 (Sep-16 to Sep-17) while the aquifer infiltration process starts at the beginning of 2016 or even before for the reference case. This fact shows that it must be some anticipation for the water management on the catchments, that will also depend of the rainfall-runoff process, which is not part of this internship.

6. Conclusions

The current exploitation conditions of both Elqui and Pan de Azúcar aquifers are not sustainable anymore. This is a well-known fact and it is supported by the Reference Case results, which best approximate the current situation. But the hydrological conditions of the region, efficient management of the water resources, and the implementation of some infiltration infrastructure can stop the depletion of the groundwater resources and even improve the water table levels.

Scenario C results show that, even without jeopardizing the irrigation water demands under an average "*desmarque*", there is a high potential for artificial infiltration of the aquifers after an extreme precipitation event (such as happened in 2017), making clever use of the Puclaro reservoir.

Even with the increase in the infiltration capacity in both Elqui and Pan de Azúcar aquifers, there is still a surplus of water after a big precipitation event that reaches the sea, without making any profit from it, leaving some space for enhancing the infiltration capacity at the Elqui aquifer. Even though the situation of this last aquifer is not as fragile as the Pan de Azúcar, the Elqui aquifer is of big importance for the wetlands in the coastal area, which also need to be protected from saltwater intrusion.

This study has shown the technical possibilities and limitations of the optimization of a combined management of reservoir and aquifers in the Elqui basin and Pan de Azúcar aquifer. In case of the application of these results in real life, all the above will need the intensive participation of the local stakeholders ("*Junta de Vigilancia del Río Elqui*", local authorities, water users, and environmental organizations), to adapt the proposed solutions to the local conditions, the diffusion of them among the community and lastly the implementation of them.

7. And now what? Future steps

There are still some interesting challenges in the future for this project that can improve the simulation and can also change the scope of this research.

Steps for the future are:

- Coupling the surface water model (WEAP or a new WFlow model) and subsurface water (iMOD) models to improve the input data used by the FORMA model. This step is debatable since it could happen that the effort on coupling both surface and subsurface models is way too much compared with the gain in accuracy of the data.
- For the users, information on the depth of the groundwater table of the aquifers is more relevant than the volume. A needed step in the future should be to relate the computed volumes in the aquifers with the corresponding water table depth.

- The extractions of both Elqui and Pan de Azúcar aquifers are currently modeled as an input value. Relating this to the previous point, the wells extractions can be restricted depending on the water table depth, in case the water level goes below the well's pumps. This could be accomplished by the coupling of the groundwater model to the RTC-Tools or/ and by including direct water level measurements (real-time data)
- Because the Pan de Azúcar infiltration is done through the existing pumping wells, a new condition of "switch on-off" should be included for the extraction-infiltration on the wells.
- At some point, the model should start including forecast data for the precipitation (input water in the Puclaro reservoir) in order to enhance the decision-making of the stakeholders. This challenge comes also with the following question: How much time of future prediction is needed for a proper decision-making in the long term for the basin? Since the longer the forecast time, the less certain the data predicted. An important part to add here is the Hydrological model required for a well representation of the rainfall-runoff (inflow to the reservoir) process.
- The model can later be set up to optimize the value of the season's ''*desmarque*" in consideration of the corresponding span of future information.
- Lastly, the main objective of this project consists of the development of a new tool that can help the decision-makers of the basin to determine the "*desmarque*" of the next season not only considering the surface water, but also the state of the aquifers. In this sense, could be interesting to couple both groundwater and surface water models directly with RTC-Tools model, and check the advantage of this.

Appendix A
DGA fluviometric statistics
“Rio Elqui en Algarrobal”
2010 – 2019

CAUDALES MEDIOS MENSUALES (m3/s)
PERIODO: 01/01/2010 - 31/12/2019

Estación: RIO ELQUI EN ALGARROBAL
Codigo BNA: 04320001-1
Cuenca: RIO ELQUI
SubCuenca: Rio Elqui Medio (Jta Turbio, Claro y Q El Arrayan)

Altitud (msnm): 760
Latitud S: 30° 00' 02"
Longitud W: 70° 35' 13"

UTM Norte (mts): 6680103
UTM Este (mts): 346933
Área de Drenaje (km2): 5729,00

AÑO	ENE	I	FEB	I	MAR	I	ABR	I	MAY	I	JUN	I	JUL	I	AGO	I	SEP	I	OCT	I	NOV	I	DIC	I
2010	4,32		4,57		5,59		5,06	%	3,60		3,06		3,52		3,11		2,79		2,95		2,41		2,38	
2011	2,62		2,60		2,81		2,57		2,91		3,71		3,75		3,46		2,89		2,60		2,27		2,74	
2012	2,94		2,54		2,63		2,97		3,34		3,48		3,37		3,34		3,61		3,54		3,29		2,87	
2013	2,72		3,03		3,06		3,37		3,25		3,29		3,29		3,13		2,81		2,49		2,79		2,79	
2014	3,65		4,38		4,02		3,31		2,87		3,45		3,12		2,86		2,60		2,30		2,37		2,26	
2015	2,05		2,05		3,04		2,79	%	2,61		2,73		3,32		4,23		5,21		5,38		7,01		8,50	%
2016	10,49	@	7,00		6,31		6,67		6,87	%	8,69		7,94		8,52		10,48	%	14,57	%	25,25		32,15	
2017	28,42		18,25		13,62		11,92		14,61		13,52		11,98		10,20		8,37		7,38		7,53		7,58	
2018	6,99		6,80		6,13		6,44		6,76		7,34		6,50		5,79		4,89		4,57		4,31		3,98	
2019	4,13		4,26		4,31	%	4,81	%	5,32	%	5,66		5,09	%	4,35	*	3,98		3,11		2,53		2,62	

INDICADORES:
- * : 1 - 10 Días con Información en el Mes
- @ : 11 - 20 Días con Información en el Mes
- % : Más de 20 Días con Información en el Mes

Appendix B
WEAP Model demands

WEAP Model demands - Elqui Medio

Año	Mes	"ELQ_B_Agua de Pangue[Cubic Meter]"	"ELQ_B_Maiten Alto o Delirio[Cubic Meter]"	"ELQ_B_Quiscal[Cubic Meter]"	"ELQ_B_Casuto[Cubic Meter]"	"ELQ_B_Marqueza[Cubic Meter]"	"ELQ_B_La Calera[Cubic Meter]"	"ELQ_B_Titon[Cubic Meter]"	"ELQ_B_San Pedro Nolasco[Cubic Meter]"	"ELQ_B_Cutun o Rojas[Cubic Meter]"	"ELQ_B_Bellavista[Cubic Meter]"	"ELQ_B_El Romero[Cubic Meter]"	"ELQ_B_Hinojal[Cubic Meter]"	"ELQ_B_Saturno[Cubic Meter]"	"ELQ_B_Quilacan[Cubic Meter]"	"ELQ_B_Herradura[Cubic Meter]"	"ELQ_B_Altovalsol[Cubic Meter]"	"ELQ_B_Pampa[Cubic Meter]"	"ELQ_B_Coquimbito[Cubic Meter]"	DEMANDS (m3/mes)		DEMANDS (m3/s)	
																				TOTAL	**CANAL BELLAVISTA**	**TOTAL**	**CANAL BELLAVISTA**
2010	1	23037,5	370505	39567,9	10069,9	289864	468737	187153	386987	247619	6723106	866230	199864	138447	11272,6	54426,6	308242	155984	183678	**3941684,5**	**6723106**	**1,47**	**2,51**
2010	2	19221,3	301212	34256,5	8239,7	233390	371394	140114	258671	202209	5695063	602204	140500	79475,1	5435,88	33904,8	258420	89511,4	77995,3	**2856153,98**	**5695063**	**1,18**	**2,35**
2010	3	15154,9	234714	27622,2	6664,77	186920	301110	108877	246735	166781	4532449	558298	130314	83262,4	6277,78	34050,3	214591	94472,3	100099	**2515943,65**	**4532449**	**0,94**	**1,69**
2010	4	10266	154167	20484,7	4327,1	126966	274225	85297,3	458803	144845	3192479	999607	221678	221898	21166,9	80924,2	205624	257193	393287	**3680759,2**	**3192479**	**1,42**	**1,23**
2010	5	6435,37	84224,7	14759,4	2769,05	72442,6	139535	28048,1	186347	86507,3	2133412	421798	96573,6	77438,5	6456,43	30713,4	129031	90879,5	117236	**1591194,95**	**2133412**	**0,59**	**0,80**
2010	6	4953,52	56128,9	12798,1	2106,76	50112,3	92080,5	5661,93	101086	66084	1741188	243898	57726,9	33488,5	1968,95	15564,5	104869	40646,1	33686,5	**922860,46**	**1741188**	**0,36**	**0,67**
2010	7	5222,23	59161,6	13492,4	2176,63	51903,6	96743,4	5850,23	104481	69072,4	1835644	254867	60057,4	34816,9	2033,17	16268,8	110447	42377,3	34697,5	**963668,56**	**1835644**	**0,36**	**0,69**
2010	8	7423,51	102907	15939,8	3330,74	88767,7	160404	40148,6	201884	96768,9	2386179	448551	103496	81622	6835,86	32060,1	137192	94946,6	122768	**1745045,81**	**2386179**	**0,65**	**0,89**
2010	9	11237,6	172260	21999,3	4942,26	146355	319517	103268	575896	166473	3465409	1235751	274268	282222	27310,8	101675	231880	326396	509605	**4511055,96**	**3465409**	**1,74**	**1,34**
2010	10	15551,1	247753	28562,2	7010,27	209160	432051	153205	737547	220941	4665957	1571017	349642	357364	34680,7	128111	295380	411711	644250	**5843936,27**	**4665957**	**2,18**	**1,74**
2010	11	18400,3	310534	30404,7	8775,61	263838	501132	202692	800394	249371	5287232	1672325	374821	380057	37164,9	134618	308044	434477	685793	**6412841,51**	**5287232**	**2,47**	**2,04**
2010	12	22074,6	370719	34819,5	10603,2	302876	439050	198595	310580	231370	6228891	647660	157070	88783,9	6670,92	34698,4	255971	94737	94710,5	**3300989,02**	**6228891**	**1,23**	**2,33**
2011	1	23037,5	370505	39567,9	10069,9	289864	468737	187153	386987	247619	6723106	866230	199864	138447	11272,6	54426,6	308242	155984	183678	**3941684,5**	**6723106**	**1,47**	**2,51**
2011	2	19221,3	301212	34256,5	8239,7	233390	371394	140114	258671	202209	5695063	602204	140500	79475,1	5435,88	33904,8	258420	89511,4	77995,3	**2856153,98**	**5695063**	**1,18**	**2,35**
2011	3	15154,9	234714	27622,2	6664,77	186920	301110	108877	246735	166781	4532449	558298	130314	83262,4	6277,78	34050,3	214591	94472,3	100099	**2515943,65**	**4532449**	**0,94**	**1,69**
2011	4	10266	154167	20484,7	4327,1	126966	274225	85297,3	458803	144845	3192479	999607	221678	221898	21166,9	80924,2	205624	257193	393287	**3680759,2**	**3192479**	**1,42**	**1,23**
2011	5	6435,37	84224,7	14759,4	2769,05	72442,6	139535	28048,1	186347	86507,3	2133412	421798	96573,6	77438,5	6456,43	30713,4	129031	90879,5	117236	**1591194,95**	**2133412**	**0,59**	**0,80**
2011	6	4953,52	56128,9	12798,1	2106,76	50112,3	92080,5	5661,93	101086	66084	1741188	243898	57726,9	33488,5	1968,95	15564,5	104869	40646,1	33686,5	**922860,46**	**1741188**	**0,36**	**0,67**
2011	7	5222,23	59161,6	13492,4	2176,63	51903,6	96743,4	5850,23	104481	69072,4	1835644	254867	60057,4	34816,9	2033,17	16268,8	110447	42377,3	34697,5	**963668,56**	**1835644**	**0,36**	**0,69**
2011	8	7423,51	102907	15939,8	3330,74	88767,7	160404	40148,6	201884	96768,9	2386179	448551	103496	81622	6835,86	32060,1	137192	94946,6	122768	**1745045,81**	**2386179**	**0,65**	**0,89**
2011	9	11237,6	172260	21999,3	4942,26	146355	319517	103268	575896	166473	3465409	1235751	274268	282222	27310,8	101675	231880	326396	509605	**4511055,96**	**3465409**	**1,74**	**1,34**
2011	10	15551,1	247753	28562,2	7010,27	209160	432051	153205	737547	220941	4665957	1571017	349642	357364	34680,7	128111	295380	411711	644250	**5843936,27**	**4665957**	**2,18**	**1,74**
2011	11	18400,3	310534	30404,7	8775,61	263838	501132	202692	800394	249371	5287232	1672325	374821	380057	37164,9	134618	308044	434477	685793	**6412841,51**	**5287232**	**2,47**	**2,04**
2011	12	22074,6	370719	34819,5	10603,2	302876	439050	198595	310580	231370	6228891	647660	157070	88783,9	6670,92	34698,4	255971	94737	94710,5	**3300989,02**	**6228891**	**1,23**	**2,33**
2012	1	23037,5	370505	39567,9	10069,9	289864	468737	187153	386987	247619	6723106	866230	199864	138447	11272,6	54426,6	308242	155984	183678	**3941684,5**	**6723106**	**1,47**	**2,51**
2012	2	19221,3	301212	34256,5	8239,7	233390	371394	140114	258671	202209	5695063	602204	140500	79475,1	5435,88	33904,8	258420	89511,4	77995,3	**2856153,98**	**5695063**	**1,14**	**2,27**
2012	3	15154,9	234714	27622,2	6664,77	186920	301110	108877	246735	166781	4532449	558298	130314	83262,4	6277,78	34050,3	214591	94472,3	100099	**2515943,65**	**4532449**	**0,94**	**1,69**
2012	4	10266	154167	20484,7	4327,1	126966	274225	85297,3	458803	144845	3192479	999607	221678	221898	21166,9	80924,2	205624	257193	393287	**3680759,2**	**3192479**	**1,42**	**1,23**
2012	5	6435,37	84224,7	14759,4	2769,05	72442,6	139535	28048,1	186347	86507,3	2133412	421798	96573,6	77438,5	6456,43	30713,4	129031	90879,5	117236	**1591194,95**	**2133412**	**0,59**	**0,80**
2012	6	4953,52	56128,9	12798,1	2106,76	50112,3	92080,5	5661,93	101086	66084	1741188	243898	57726,9	33488,5	1968,95	15564,5	104869	40646,1	33686,5	**922860,46**	**1741188**	**0,36**	**0,67**
2012	7	5222,23	59161,6	13492,4	2176,63	51903,6	96743,4	5850,23	104481	69072,4	1835644	254867	60057,4	34816,9	2033,17	16268,8	110447	42377,3	34697,5	**963668,56**	**1835644**	**0,36**	**0,69**
2012	8	7423,51	102907	15939,8	3330,74	88767,7	160404	40148,6	201884	96768,9	2386179	448551	103496	81622	6835,86	32060,1	137192	94946,6	122768	**1745045,81**	**2386179**	**0,65**	**0,89**
2012	9	11237,6	172260	21999,3	4942,26	146355	319517	103268	575896	166473	3465409	1235751	274268	282222	27310,8	101675	231880	326396	509605	**4511055,96**	**3465409**	**1,74**	**1,34**
2012	10	15551,1	247753	28562,2	7010,27	209160	432051	153205	737547	220941	4665957	1571017	349642	357364	34680,7	128111	295380	411711	644250	**5843936,27**	**4665957**	**2,18**	**1,74**
2012	11	18400,3	310534	30404,7	8775,61	263838	501132	202692	800394	249371	5287232	1672325	374821	380057	37164,9	134618	308044	434477	685793	**6412841,51**	**5287232**	**2,47**	**2,04**
2012	12	22074,6	370719	34819,5	10603,2	302876	439050	198595	310580	231370	6228891	647660	157070	88783,9	6670,92	34698,4	255971	94737	94710,5	**3300989,02**	**6228891**	**1,23**	**2,33**
2013	1	23037,5	370505	39567,9	10069,9	289864	468737	187153	386987	247619	6723106	866230	199864	138447	11272,6	54426,6	308242	155984	183678	**3941684,5**	**6723106**	**1,47**	**2,51**
2013	2	19221,3	301212	34256,5	8239,7	233390	371394	140114	258671	202209	5695063	602204	140500	79475,1	5435,88	33904,8	258420	89511,4	77995,3	**2856153,98**	**5695063**	**1,18**	**2,35**
2013	3	15154,9	234714	27622,2	6664,77	186920	301110	108877	246735	166781	4532449	558298	130314	83262,4	6277,78	34050,3	214591	94472,3	100099	**2515943,65**	**4532449**	**0,94**	**1,69**
2013	4	10266	154167	20484,7	4327,1	126966	274225	85297,3	458803	144845	3192479	999607	221678	221898	21166,9	80924,2	205624	257193	393287	**3680759,2**	**3192479**	**1,42**	**1,23**
2013	5	6435,37	84224,7	14759,4	2769,05	72442,6	139535	28048,1	186347	86507,3	2133412	421798	96573,6	77438,5	6456,43	30713,4	129031	90879,5	117236	**1591194,95**	**2133412**	**0,59**	**0,80**
2013	6	4953,52	56128,9	12798,1	2106,76	50112,3	92080,5	5661,93	101086	66084	1741188	243898	57726,9	33488,5	1968,95	15564,5	104869	40646,1	33686,5	**922860,46**	**1741188**	**0,36**	**0,67**
2013	7	5222,23	59161,6	13492,4	2176,63	51903,6	96743,4	5850,23	104481	69072,4	1835644	254867	60057,4	34816,9	2033,17	16268,8	110447	42377,3	34697,5	**963668,56**	**1835644**	**0,36**	**0,69**
2013	8	7423,51	102907	15939,8	3330,74	88767,7	160404	40148,6	201884	96768,9	2386179	448551	103496	81622	6835,86	32060,1	137192	94946,6	122768	**1745045,81**	**2386179**	**0,65**	**0,89**
2013	9	11237,6	172260	21999,3	4942,26	146355	319517	103268	575896	166473	3465409	1235751	274268	282222	27310,8	101675	231880	326396	509605	**4511055,96**	**3465409**	**1,74**	**1,34**
2013	10	15551,1	247753	28562,2	7010,27	209160	432051	153205	737547	220941	4665957	1571017	349642	357364	34680,7	128111	295380	411711	644250	**5843936,27**	**4665957**	**2,18**	**1,74**

Año	Mes	"ELQ_B_Agua de Pangue[Cubic Meter]"	"ELQ_B_Maiten Alto o Delirio[Cubic Meter]"	"ELQ_B_Quiscal[Cubic Meter]"	"ELQ_B_Casuto[Cubic Meter]"	"ELQ_B_Marqueza[Cubic Meter]"	"ELQ_B_La Calera[Cubic Meter]"	"ELQ_B_Titon[Cubic Meter]"	"ELQ_B_San Pedro Nolasco[Cubic Meter]"	"ELQ_B_Cutun o Rojas[Cubic Meter]"	"ELQ_B_Bellavista[Cubic Meter]"	"ELQ_B_El Romero[Cubic Meter]"	"ELQ_B_Hinojal[Cubic Meter]"	"ELQ_B_Saturno[Cubic Meter]"	"ELQ_B_Quilacan[Cubic Meter]"	"ELQ_B_Herradura[Cubic Meter]"	"ELQ_B_Altovalsol[Cubic Meter]"	"ELQ_B_Pampa[Cubic Meter]"	"ELQ_B_Coquimbito[Cubic Meter]"	DEMANDS (m3/mes)		DEMANDS (m3/s)	
																				TOTAL	CANAL BELLAVISTA	TOTAL	CANAL BELLAVISTA
2013	11	18400,3	310534	30404,7	8775,61	263838	501132	202692	800394	249371	5287232	1672325	374821	380057	37164,9	134618	308044	434477	685793	**6412841,51**	**5287232**	**2,47**	**2,04**
2013	12	22074,6	370719	34819,5	10603,2	302876	439050	198595	310580	231370	6228891	647660	157070	88783,9	6670,92	34698,4	255971	94737	94710,5	**3300989,02**	**6228891**	**1,23**	**2,33**
2014	1	23037,5	370505	39567,9	10069,9	289864	468737	187153	386987	247619	6723106	866230	199864	138447	11272,6	54426,6	308242	155984	183678	**3941684,5**	**6723106**	**1,47**	**2,51**
2014	2	19221,3	301212	34256,5	8239,7	233390	371394	140114	258671	202209	5695063	602204	140500	79475,1	5435,88	33904,8	258420	89511,4	77995,3	**2856153,98**	**5695063**	**1,18**	**2,35**
2014	3	15154,9	234714	27622,2	6664,77	186920	301110	108877	246735	166781	4532449	558298	130314	83262,4	6277,78	34050,3	214591	94472,3	100099	**2515943,65**	**4532449**	**0,94**	**1,69**
2014	4	10266	154167	20484,7	4327,1	126966	274225	85297,3	458803	144845	3192479	999607	221678	221898	21166,9	80924,2	205624	257193	393287	**3680759,2**	**3192479**	**1,42**	**1,23**
2014	5	6435,37	84224,7	14759,4	2769,05	72442,6	139535	28048,1	186347	86507,3	2133412	421798	96573,6	77438,5	6456,43	30713,4	129031	90879,5	117236	**1591194,95**	**2133412**	**0,59**	**0,80**
2014	6	4953,52	56128,9	12798,1	2106,76	50112,3	92080,5	5661,93	101086	66084	1741188	243898	57726,9	33488,5	1968,95	15564,5	104869	40646,1	33686,5	**922860,46**	**1741188**	**0,36**	**0,67**
2014	7	5222,23	59161,6	13492,4	2176,63	51903,6	96743,4	5850,23	104481	69072,4	1835644	254867	60057,4	34816,9	2033,17	16268,8	110447	42377,3	34697,5	**963668,56**	**1835644**	**0,36**	**0,69**
2014	8	7423,51	102907	15939,8	3330,74	88767,7	160404	40148,6	201884	96768,9	2386179	448551	103496	81622	6835,86	32060,1	137192	94946,6	122768	**1745045,81**	**2386179**	**0,65**	**0,89**
2014	9	11237,6	172260	21999,3	4942,26	146355	319517	103268	575896	166473	3465409	1235751	274268	282222	27310,8	101675	231880	326396	509605	**4511055,96**	**3465409**	**1,74**	**1,34**
2014	10	15551,1	247753	28562,2	7010,27	209160	432051	153205	737547	220941	4665957	1571017	349642	357364	34680,7	128111	295380	411711	644250	**5843936,27**	**4665957**	**2,18**	**1,74**
2014	11	18400,3	310534	30404,7	8775,61	263838	501132	202692	800394	249371	5287232	1672325	374821	380057	37164,9	134618	308044	434477	685793	**6412841,51**	**5287232**	**2,47**	**2,04**
2014	12	22074,6	370719	34819,5	10603,2	302876	439050	198595	310580	231370	6228891	647660	157070	88783,9	6670,92	34698,4	255971	94737	94710,5	**3300989,02**	**6228891**	**1,23**	**2,33**
2015	1	23037,5	370505	39567,9	10069,9	289864	468737	187153	386987	247619	6723106	866230	199864	138447	11272,6	54426,6	308242	155984	183678	**3941684,5**	**6723106**	**1,47**	**2,51**
2015	2	19221,3	301212	34256,5	8239,7	233390	371394	140114	258671	202209	5695063	602204	140500	79475,1	5435,88	33904,8	258420	89511,4	77995,3	**2856153,98**	**5695063**	**1,18**	**2,35**
2015	3	15154,9	234714	27622,2	6664,77	186920	301110	108877	246735	166781	4532449	558298	130314	83262,4	6277,78	34050,3	214591	94472,3	100099	**2515943,65**	**4532449**	**0,94**	**1,69**
2015	4	10266	154167	20484,7	4327,1	126966	274225	85297,3	458803	144845	3192479	999607	221678	221898	21166,9	80924,2	205624	257193	393287	**3680759,2**	**3192479**	**1,42**	**1,23**
2015	5	6435,37	84224,7	14759,4	2769,05	72442,6	139535	28048,1	186347	86507,3	2133412	421798	96573,6	77438,5	6456,43	30713,4	129031	90879,5	117236	**1591194,95**	**2133412**	**0,59**	**0,80**
2015	6	4953,52	56128,9	12798,1	2106,76	50112,3	92080,5	5661,93	101086	66084	1741188	243898	57726,9	33488,5	1968,95	15564,5	104869	40646,1	33686,5	**922860,46**	**1741188**	**0,36**	**0,67**
2015	7	5222,23	59161,6	13492,4	2176,63	51903,6	96743,4	5850,23	104481	69072,4	1835644	254867	60057,4	34816,9	2033,17	16268,8	110447	42377,3	34697,5	**963668,56**	**1835644**	**0,36**	**0,69**
2015	8	7423,51	102907	15939,8	3330,74	88767,7	160404	40148,6	201884	96768,9	2386179	448551	103496	81622	6835,86	32060,1	137192	94946,6	122768	**1745045,81**	**2386179**	**0,65**	**0,89**
2015	9	11237,6	172260	21999,3	4942,26	146355	319517	103268	575896	166473	3465409	1235751	274268	282222	27310,8	101675	231880	326396	509605	**4511055,96**	**3465409**	**1,74**	**1,34**
2015	10	15551,1	247753	28562,2	7010,27	209160	432051	153205	737547	220941	4665957	1571017	349642	357364	34680,7	128111	295380	411711	644250	**5843936,27**	**4665957**	**2,18**	**1,74**
2015	11	18400,3	310534	30404,7	8775,61	263838	501132	202692	800394	249371	5287232	1672325	374821	380057	37164,9	134618	308044	434477	685793	**6412841,51**	**5287232**	**2,47**	**2,04**
2015	12	22074,6	370719	34819,5	10603,2	302876	439050	198595	310580	231370	6228891	647660	157070	88783,9	6670,92	34698,4	255971	94737	94710,5	**3300989,02**	**6228891**	**1,23**	**2,33**
2016	1	23037,5	370505	39567,9	10069,9	289864	468737	187153	386987	247619	6723106	866230	199864	138447	11272,6	54426,6	308242	155984	183678	**3941684,5**	**6723106**	**1,47**	**2,51**
2016	2	19221,3	301212	34256,5	8239,7	233390	371394	140114	258671	202209	5695063	602204	140500	79475,1	5435,88	33904,8	258420	89511,4	77995,3	**2856153,98**	**5695063**	**1,14**	**2,27**
2016	3	15154,9	234714	27622,2	6664,77	186920	301110	108877	246735	166781	4532449	558298	130314	83262,4	6277,78	34050,3	214591	94472,3	100099	**2515943,65**	**4532449**	**0,94**	**1,69**
2016	4	10266	154167	20484,7	4327,1	126966	274225	85297,3	458803	144845	3192479	999607	221678	221898	21166,9	80924,2	205624	257193	393287	**3680759,2**	**3192479**	**1,42**	**1,23**
2016	5	6435,37	84224,7	14759,4	2769,05	72442,6	139535	28048,1	186347	86507,3	2133412	421798	96573,6	77438,5	6456,43	30713,4	129031	90879,5	117236	**1591194,95**	**2133412**	**0,59**	**0,80**
2016	6	4953,52	56128,9	12798,1	2106,76	50112,3	92080,5	5661,93	101086	66084	1741188	243898	57726,9	33488,5	1968,95	15564,5	104869	40646,1	33686,5	**922860,46**	**1741188**	**0,36**	**0,67**
2016	7	5222,23	59161,6	13492,4	2176,63	51903,6	96743,4	5850,23	104481	69072,4	1835644	254867	60057,4	34816,9	2033,17	16268,8	110447	42377,3	34697,5	**963668,56**	**1835644**	**0,36**	**0,69**
2016	8	7423,51	102907	15939,8	3330,74	88767,7	160404	40148,6	201884	96768,9	2386179	448551	103496	81622	6835,86	32060,1	137192	94946,6	122768	**1745045,81**	**2386179**	**0,65**	**0,89**
2016	9	11237,6	172260	21999,3	4942,26	146355	319517	103268	575896	166473	3465409	1235751	274268	282222	27310,8	101675	231880	326396	509605	**4511055,96**	**3465409**	**1,74**	**1,34**
2016	10	15551,1	247753	28562,2	7010,27	209160	432051	153205	737547	220941	4665957	1571017	349642	357364	34680,7	128111	295380	411711	644250	**5843936,27**	**4665957**	**2,18**	**1,74**
2016	11	18400,3	310534	30404,7	8775,61	263838	501132	202692	800394	249371	5287232	1672325	374821	380057	37164,9	134618	308044	434477	685793	**6412841,51**	**5287232**	**2,47**	**2,04**
2016	12	22074,6	370719	34819,5	10603,2	302876	439050	198595	310580	231370	6228891	647660	157070	88783,9	6670,92	34698,4	255971	94737	94710,5	**3300989,02**	**6228891**	**1,23**	**2,33**
2017	1	23037,5	370505	39567,9	10069,9	289864	468737	187153	386987	247619	6723106	866230	199864	138447	11272,6	54426,6	308242	155984	183678	**3941684,5**	**6723106**	**1,47**	**2,51**
2017	2	19221,3	301212	34256,5	8239,7	233390	371394	140114	258671	202209	5695063	602204	140500	79475,1	5435,88	33904,8	258420	89511,4	77995,3	**2856153,98**	**5695063**	**1,18**	**2,35**
2017	3	15154,9	234714	27622,2	6664,77	186920	301110	108877	246735	166781	4532449	558298	130314	83262,4	6277,78	34050,3	214591	94472,3	100099	**2515943,65**	**4532449**	**0,94**	**1,69**
2017	4	10266	154167	20484,7	4327,1	126966	274225	85297,3	458803	144845	3192479	999607	221678	221898	21166,9	80924,2	205624	257193	393287	**3680759,2**	**3192479**	**1,42**	**1,23**
2017	5	6435,37	84224,7	14759,4	2769,05	72442,6	139535	28048,1	186347	86507,3	2133412	421798	96573,6	77438,5	6456,43	30713,4	129031	90879,5	117236	**1591194,95**	**2133412**	**0,59**	**0,80**
2017	6	4953,52	56128,9	12798,1	2106,76	50112,3	92080,5	5661,93	101086	66084	1741188	243898	57726,9	33488,5	1968,95	15564,5	104869	40646,1	33686,5	**922860,46**	**1741188**	**0,36**	**0,67**
2017	7	5222,23	59161,6	13492,4	2176,63	51903,6	96743,4	5850,23	104481	69072,4	1835644	254867	60057,4	34816,9	2033,17	16268,8	110447	42377,3	34697,5	**963668,56**	**1835644**	**0,36**	**0,69**
2017	8	7423,51	102907	15939,8	3330,74	88767,7	160404	40148,6	201884	96768,9	2386179	448551	103496	81622	6835,86	32060,1	137192	94946,6	122768	**1745045,81**	**2386179**	**0,65**	**0,89**
2017	9	11237,6	172260	21999,3	4942,26	146355	319517	103268	575896	166473	3465409	1235751	274268	282222	27310,8	101675	231880	326396	509605	**4511055,96**	**3465409**	**1,74**	**1,34**
2017	10	15551,1	247753	28562,2	7010,27	209160	432051	153205	737547	220941	4665957	1571017	349642	357364	34680,7	128111	295380	411711	644250	**5843936,27**	**4665957**	**2,18**	**1,74**
2017	11	18400,3	310534	30404,7	8775,61	263838	501132	202692	800394	249371	5287232	1672325	374821	380057	37164,9	134618	308044	434477	685793	**6412841,51**	**5287232**	**2,47**	**2,04**
2017	12	22074,6	370719	34819,5	10603,2	302876	439050	198595	310580	231370	6228891	647660	157070	88783,9	6670,92	34698,4	255971	94737	94710,5	**3300989,02**	**6228891**	**1,23**	**2,33**
2018	1	23037,5	370505	39567,9	10069,9	289864	468737	187153	386987	247619	6723106	866230	199864	138447	11272,6	54426,6	308242	155984	183678	**3941684,5**	**6723106**	**1,47**	**2,51**
2018	2	19221,3	301212	34256,5	8239,7	233390	371394	140114	258671	202209	5695063	602204	140500	79475,1	5435,88	33904,8	258420	89511,4	77995,3	**2856153,98**	**5695063**	**1,18**	**2,35**
2018	3	15154,9	234714	27622,2	6664,77	186920	301110	108877	246735	166781	4532449	558298	130314	83262,4	6277,78	34050,3	214591	94472,3	100099	**2515943,65**	**4532449**	**0,94**	**1,69**
2018	4	10266	154167	20484,7	4327,1	126966	274225	85297,3	458803	144845	3192479	999607	221678	221898	21166,9	80924,2	205624	257193	393287	**3680759,2**	**3192479**	**1,42**	**1,23**

Año	Mes	"ELQ_B_Agua de Pangue[Cubic Meter]"	"ELQ_B_Maiten Alto o Delirio[Cubic Meter]"	"ELQ_B_Quiscal[Cubic Meter]"	"ELQ_B_Casuto[Cubic Meter]"	"ELQ_B_Marqueza[Cubic Meter]"	"ELQ_B_La Calera[Cubic Meter]"	"ELQ_B_Titon[Cubic Meter]"	"ELQ_B_San Pedro Nolasco[Cubic Meter]"	"ELQ_B_Cutun o Rojas[Cubic Meter]"	"ELQ_B_Bellavista[Cubic Meter]"	"ELQ_B_El Romero[Cubic Meter]"	"ELQ_B_Hinojal[Cubic Meter]"	"ELQ_B_Saturno[Cubic Meter]"	"ELQ_B_Quilacan[Cubic Meter]"	"ELQ_B_Herradura[Cubic Meter]"	"ELQ_B_Altovalsol[Cubic Meter]"	"ELQ_B_Pampa[Cubic Meter]"	"ELQ_B_Coquimbito[Cubic Meter]"
2018	5	6435,37	84224,7	14759,4	2769,05	72442,6	139535	28048,1	186347	86507,3	2133412	421798	96573,6	77438,5	6456,43	30713,4	129031	90879,5	117236
2018	6	4953,52	56128,9	12798,1	2106,76	50112,3	92080,5	5661,93	101086	66084	1741188	243898	57726,9	33488,5	1968,95	15564,5	104869	40646,1	33686,5
2018	7	5222,23	59161,6	13492,4	2176,63	51903,6	96743,4	5850,23	104481	69072,4	1835644	254867	60057,4	34816,9	2033,17	16268,8	110447	42377,3	34697,5
2018	8	7423,51	102907	15939,8	3330,74	88767,7	160404	40148,6	201884	96768,9	2386179	448551	103496	81622	6835,86	32060,1	137192	94946,6	122768
2018	9	11237,6	172260	21999,3	4942,26	146355	319517	103268	575896	166473	3465409	1235751	274268	282222	27310,8	101675	231880	326396	509605
2018	10	15551,1	247753	28562,2	7010,27	209160	432051	153205	737547	220941	4665957	1571017	349642	357364	34680,7	128111	295380	411711	644250
2018	11	18400,3	310534	30404,7	8775,61	263838	501132	202692	800394	249371	5287232	1672325	374821	380057	37164,9	134618	308044	434477	685793
2018	12	22074,6	370719	34819,5	10603,2	302876	439050	198595	310580	231370	6228891	647660	157070	88783,9	6670,92	34698,4	255971	94737	94710,5
2019	1	23037,5	370505	39567,9	10069,9	289864	468737	187153	386987	247619	6723106	866230	199864	138447	11272,6	54426,6	308242	155984	183678
2019	2	19221,3	301212	34256,5	8239,7	233390	371394	140114	258671	202209	5695063	602204	140500	79475,1	5435,88	33904,8	258420	89511,4	77995,3
2019	3	15154,9	234714	27622,2	6664,77	186920	301110	108877	246735	166781	4532449	558298	130314	83262,4	6277,78	34050,3	214591	94472,3	100099
2019	4	10266	154167	20484,7	4327,1	126966	274225	85297,3	458803	144845	3192479	999607	221678	221898	21166,9	80924,2	205624	257193	393287
2019	5	6435,37	84224,7	14759,4	2769,05	72442,6	139535	28048,1	186347	86507,3	2133412	421798	96573,6	77438,5	6456,43	30713,4	129031	90879,5	117236
2019	6	4953,52	56128,9	12798,1	2106,76	50112,3	92080,5	5661,93	101086	66084	1741188	243898	57726,9	33488,5	1968,95	15564,5	104869	40646,1	33686,5
2019	7	5222,23	59161,6	13492,4	2176,63	51903,6	96743,4	5850,23	104481	69072,4	1835644	254867	60057,4	34816,9	2033,17	16268,8	110447	42377,3	34697,5
2019	8	7423,51	102907	15939,8	3330,74	88767,7	160404	40148,6	201884	96768,9	2386179	448551	103496	81622	6835,86	32060,1	137192	94946,6	122768
2019	9	11237,6	172260	21999,3	4942,26	146355	319517	103268	575896	166473	3465409	1235751	274268	282222	27310,8	101675	231880	326396	509605
2019	10	15551,1	247753	28562,2	7010,27	209160	432051	153205	737547	220941	4665957	1571017	349642	357364	34680,7	128111	295380	411711	644250
2019	11	18400,3	310534	30404,7	8775,61	263838	501132	202692	800394	249371	5287232	1672325	374821	380057	37164,9	134618	308044	434477	685793
2019	12	22074,6	370719	34819,5	10603,2	302876	439050	198595	310580	231370	6228891	647660	157070	88783,9	6670,92	34698,4	255971	94737	94710,5

DEMANDS (m3/mes)		**DEMANDS (m3/s)**	
TOTAL	**CANAL BELLAVISTA**	**TOTAL**	**CANAL BELLAVISTA**
1591194,95	**2133412**	**0,59**	**0,80**
922860,46	**1741188**	**0,36**	**0,67**
963668,56	**1835644**	**0,36**	**0,69**
1745045,81	**2386179**	**0,65**	**0,89**
4511055,96	**3465409**	**1,74**	**1,34**
5843936,27	**4665957**	**2,18**	**1,74**
6412841,51	**5287232**	**2,47**	**2,04**
3300989,02	**6228891**	**1,23**	**2,33**
3941684,5	**6723106**	**1,47**	**2,51**
2856153,98	**5695063**	**1,18**	**2,35**
2515943,65	**4532449**	**0,94**	**1,69**
3680759,2	**3192479**	**1,42**	**1,23**
1591194,95	**2133412**	**0,59**	**0,80**
922860,46	**1741188**	**0,36**	**0,67**
963668,56	**1835644**	**0,36**	**0,69**
1745045,81	**2386179**	**0,65**	**0,89**
4511055,96	**3465409**	**1,74**	**1,34**
5843936,27	**4665957**	**2,18**	**1,74**
6412841,51	**5287232**	**2,47**	**2,04**
3300989,02	**6228891**	**1,23**	**2,33**

WEAP Model demands - Elqui Bajo

Año	Mes	"ELQ_B_Culcatan[Cubic Meter]"	"ELQ_B_Callejas"	"AGUAS DEL VALLE[Cubic Meter]"	"ELQ_B_Federico Arcos"	"ELQ_B_Juan Soldado"	"ELQ_B_Particulares"	"ELQ_B_Tejar"	"ELQ_B_Vegas Norte"	DEMANDS (m3/mes)		DEMANDS (m3/s)	
										TOTAL	**AGUAS DEL VALLE**	**TOTAL**	**AGUAS DEL VALLE**
2010	1	24866	12006	1548388	23933	476765	23143,2	57423,5	53079,2	**671215,9**	**1548388**	**0,25**	**0,58**
2010	2	14665,6	7388,22	1759754	14727,9	293391	14241,9	35337,2	32663,8	**412415,54**	**1759754**	**0,17**	**0,73**
2010	3	14065,5	6829,68	1200756	13614,4	271210	13165,1	32665,6	30194,4	**381744,833**	**1200756**	**0,14**	**0,45**
2010	4	32302	14029,4	1092328	27966,5	557116	27043,6	67101,3	62024,8	**787583,66**	**1092328**	**0,30**	**0,42**
2010	5	9907,61	4337,45	1161501	8646,33	172242	8361,01	20745,6	19176,1	**243416,025**	**1161501**	**0,09**	**0,43**
2010	6	2807,88	1224,59	1189891	2441,12	48629	2360,55	5857,08	5413,97	**68734,181**	**1189891**	**0,03**	**0,46**
2010	7	2900,88	1266,21	1224128	2524,09	50281,8	2440,78	6056,14	5597,98	**71067,916**	**1224128**	**0,03**	**0,46**
2010	8	11058,7	4923,32	1214936	9814,21	195507	9490,32	23547,7	21766,2	**276107,687**	**1214936**	**0,10**	**0,45**
2010	9	41315,5	17877,6	1199299	35637,5	709927	34461,4	85506,4	79037,7	**1003763,42**	**1199299**	**0,39**	**0,46**
2010	10	53672,9	23404,9	883168	46655,6	929418	45115,8	111943	103474	**1313683,82**	**883168**	**0,49**	**0,33**
2010	11	59621,5	26301,3	1099125	52429,5	1044438	50699,2	125796	116279	**1475564,7**	**1099125**	**0,57**	**0,42**
2010	12	19447,1	9885,33	1221250	19705,6	392551	19055,3	47280,5	43703,5	**551628,19**	**1221250**	**0,21**	**0,46**
2011	1	24866	12006	1579356	23933	476765	23143,2	57423,5	53079,2	**671215,9**	**1579356**	**0,25**	**0,59**
2011	2	14665,6	7388,22	1794949	14727,9	293391	14241,9	35337,2	32663,8	**412415,54**	**1794949**	**0,17**	**0,74**
2011	3	14065,5	6829,68	1224771	13614,4	271210	13165,1	32665,6	30194,4	**381744,833**	**1224771**	**0,14**	**0,46**
2011	4	32302	14029,4	1114174	27966,5	557116	27043,6	67101,3	62024,8	**787583,66**	**1114174**	**0,30**	**0,43**
2011	5	9907,61	4337,45	1184731	8646,33	172242	8361,01	20745,6	19176,1	**243416,025**	**1184731**	**0,09**	**0,44**
2011	6	2807,88	1224,59	1213689	2441,12	48629	2360,55	5857,08	5413,97	**68734,181**	**1213689**	**0,03**	**0,47**
2011	7	2900,88	1266,21	1248610	2524,09	50281,8	2440,78	6056,14	5597,98	**71067,916**	**1248610**	**0,03**	**0,47**
2011	8	11058,7	4923,32	1239235	9814,21	195507	9490,32	23547,7	21766,2	**276107,687**	**1239235**	**0,10**	**0,46**
2011	9	41315,5	17877,6	1223285	35637,5	709927	34461,4	85506,4	79037,7	**1003763,42**	**1223285**	**0,39**	**0,47**
2011	10	53672,9	23404,9	900831	46655,6	929418	45115,8	111943	103474	**1313683,82**	**900831**	**0,49**	**0,34**
2011	11	59621,5	26301,3	1121107	52429,5	1044438	50699,2	125796	116279	**1475564,7**	**1121107**	**0,57**	**0,43**
2011	12	19447,1	9885,33	1245675	19705,6	392551	19055,3	47280,5	43703,5	**551628,19**	**1245675**	**0,21**	**0,47**
2012	1	24866	12006	1610943	23933	476765	23143,2	57423,5	53079,2	**671215,9**	**1610943**	**0,25**	**0,60**
2012	2	14665,6	7388,22	1830848	14727,9	293391	14241,9	35337,2	32663,8	**412415,54**	**1830848**	**0,16**	**0,73**
2012	3	14065,5	6829,68	1249267	13614,4	271210	13165,1	32665,6	30194,4	**381744,833**	**1249267**	**0,14**	**0,47**
2012	4	32302	14029,4	1136458	27966,5	557116	27043,6	67101,3	62024,8	**787583,66**	**1136458**	**0,30**	**0,44**
2012	5	9907,61	4337,45	1208425	8646,33	172242	8361,01	20745,6	19176,1	**243416,025**	**1208425**	**0,09**	**0,45**
2012	6	2807,88	1224,59	1237963	2441,12	48629	2360,55	5857,08	5413,97	**68734,181**	**1237963**	**0,03**	**0,48**
2012	7	2900,88	1266,21	1273582	2524,09	50281,8	2440,78	6056,14	5597,98	**71067,916**	**1273582**	**0,03**	**0,48**
2012	8	11058,7	4923,32	1264020	9814,21	195507	9490,32	23547,7	21766,2	**276107,687**	**1264020**	**0,10**	**0,47**
2012	9	41315,5	17877,6	1247751	35637,5	709927	34461,4	85506,4	79037,7	**1003763,42**	**1247751**	**0,39**	**0,48**
2012	10	53672,9	23404,9	918848	46655,6	929418	45115,8	111943	103474	**1313683,82**	**918848**	**0,49**	**0,34**
2012	11	59621,5	26301,3	1143529	52429,5	1044438	50699,2	125796	116279	**1475564,7**	**1143529**	**0,57**	**0,44**
2012	12	19447,1	9885,33	1270588	19705,6	392551	19055,3	47280,5	43703,5	**551628,19**	**1270588**	**0,21**	**0,47**
2013	1	24866	12006	1643162	23933	476765	23143,2	57423,5	53079,2	**671215,9**	**1643162**	**0,25**	**0,61**
2013	2	14665,6	7388,22	1867465	14727,9	293391	14241,9	35337,2	32663,8	**412415,54**	**1867465**	**0,17**	**0,77**
2013	3	14065,5	6829,68	1274252	13614,4	271210	13165,1	32665,6	30194,4	**381744,833**	**1274252**	**0,14**	**0,48**
2013	4	32302	14029,4	1159187	27966,5	557116	27043,6	67101,3	62024,8	**787583,66**	**1159187**	**0,30**	**0,45**
2013	5	9907,61	4337,45	1232594	8646,33	172242	8361,01	20745,6	19176,1	**243416,025**	**1232594**	**0,09**	**0,46**
2013	6	2807,88	1224,59	1262722	2441,12	48629	2360,55	5857,08	5413,97	**68734,181**	**1262722**	**0,03**	**0,49**
2013	7	2900,88	1266,21	1299054	2524,09	50281,8	2440,78	6056,14	5597,98	**71067,916**	**1299054**	**0,03**	**0,49**
2013	8	11058,7	4923,32	1289300	9814,21	195507	9490,32	23547,7	21766,2	**276107,687**	**1289300**	**0,10**	**0,48**

Año	Mes	"ELQ_B_Culcatan[Cubic Meter]"	"ELQ_B_Callejas"	"AGUAS DEL VALLE[Cubic Meter]"	"ELQ_B_Federico Arcos"	"ELQ_B_Juan Soldado"	"ELQ_B_Particulares"	"ELQ_B_Tejar"	"ELQ_B_Vegas Norte"
2013	9	41315,5	17877,6	1272706	35637,5	709927	34461,4	85506,4	79037,7
2013	10	53672,9	23404,9	937225	46655,6	929418	45115,8	111943	103474
2013	11	59621,5	26301,3	1166400	52429,5	1044438	50699,2	125796	116279
2013	12	19447,1	9885,33	1296000	19705,6	392551	19055,3	47280,5	43703,5
2014	1	24866	12006	1676025	23933	476765	23143,2	57423,5	53079,2
2014	2	14665,6	7388,22	1904814	14727,9	293391	14241,9	35337,2	32663,8
2014	3	14065,5	6829,68	1299737	13614,4	271210	13165,1	32665,6	30194,4
2014	4	32302	14029,4	1182371	27966,5	557116	27043,6	67101,3	62024,8
2014	5	9907,61	4337,45	1257246	8646,33	172242	8361,01	20745,6	19176,1
2014	6	2807,88	1224,59	1287976	2441,12	48629	2360,55	5857,08	5413,97
2014	7	2900,88	1266,21	1325035	2524,09	50281,8	2440,78	6056,14	5597,98
2014	8	11058,7	4923,32	1315086	9814,21	195507	9490,32	23547,7	21766,2
2014	9	41315,5	17877,6	1298160	35637,5	709927	34461,4	85506,4	79037,7
2014	10	53672,9	23404,9	955970	46655,6	929418	45115,8	111943	103474
2014	11	59621,5	26301,3	1189728	52429,5	1044438	50699,2	125796	116279
2014	12	19447,1	9885,33	1321920	19705,6	392551	19055,3	47280,5	43703,5
2015	1	24866	12006	1709546	23933	476765	23143,2	57423,5	53079,2
2015	2	14665,6	7388,22	1942911	14727,9	293391	14241,9	35337,2	32663,8
2015	3	14065,5	6829,68	1325732	13614,4	271210	13165,1	32665,6	30194,4
2015	4	32302	14029,4	1206018	27966,5	557116	27043,6	67101,3	62024,8
2015	5	9907,61	4337,45	1282391	8646,33	172242	8361,01	20745,6	19176,1
2015	6	2807,88	1224,59	1313736	2441,12	48629	2360,55	5857,08	5413,97
2015	7	2900,88	1266,21	1351536	2524,09	50281,8	2440,78	6056,14	5597,98
2015	8	11058,7	4923,32	1341388	9814,21	195507	9490,32	23547,7	21766,2
2015	9	41315,5	17877,6	1324123	35637,5	709927	34461,4	85506,4	79037,7
2015	10	53672,9	23404,9	975089	46655,6	929418	45115,8	111943	103474
2015	11	59621,5	26301,3	1213523	52429,5	1044438	50699,2	125796	116279
2015	12	19447,1	9885,33	1348358	19705,6	392551	19055,3	47280,5	43703,5
2016	1	24866	12006	1743737	23933	476765	23143,2	57423,5	53079,2
2016	2	14665,6	7388,22	1981769	14727,9	293391	14241,9	35337,2	32663,8
2016	3	14065,5	6829,68	1352246	13614,4	271210	13165,1	32665,6	30194,4
2016	4	32302	14029,4	1230139	27966,5	557116	27043,6	67101,3	62024,8
2016	5	9907,61	4337,45	1308039	8646,33	172242	8361,01	20745,6	19176,1
2016	6	2807,88	1224,59	1340011	2441,12	48629	2360,55	5857,08	5413,97
2016	7	2900,88	1266,21	1378566	2524,09	50281,8	2440,78	6056,14	5597,98
2016	8	11058,7	4923,32	1368215	9814,21	195507	9490,32	23547,7	21766,2
2016	9	41315,5	17877,6	1350606	35637,5	709927	34461,4	85506,4	79037,7
2016	10	53672,9	23404,9	994591	46655,6	929418	45115,8	111943	103474
2016	11	59621,5	26301,3	1237793	52429,5	1044438	50699,2	125796	116279
2016	12	19447,1	9885,33	1375326	19705,6	392551	19055,3	47280,5	43703,5
2017	1	24866	12006	1778611	23933	476765	23143,2	57423,5	53079,2
2017	2	14665,6	7388,22	2021404	14727,9	293391	14241,9	35337,2	32663,8
2017	3	14065,5	6829,68	1379291	13614,4	271210	13165,1	32665,6	30194,4
2017	4	32302	14029,4	1254741	27966,5	557116	27043,6	67101,3	62024,8
2017	5	9907,61	4337,45	1334199	8646,33	172242	8361,01	20745,6	19176,1
2017	6	2807,88	1224,59	1366811	2441,12	48629	2360,55	5857,08	5413,97
2017	7	2900,88	1266,21	1406138	2524,09	50281,8	2440,78	6056,14	5597,98

DEMANDS (m3/mes)	
TOTAL	**AGUAS DEL VALLE**
1003763,42	1272706
1313683,82	937225
1475564,7	1166400
551628,19	1296000
671215,9	1676025
412415,54	1904814
381744,833	1299737
787583,66	1182371
243416,025	1257246
68734,181	1287976
71067,916	1325035
276107,687	1315086
1003763,42	1298160
1313683,82	955970
1475564,7	1189728
551628,19	1321920
671215,9	1709546
412415,54	1942911
381744,833	1325732
787583,66	1206018
243416,025	1282391
68734,181	1313736
71067,916	1351536
276107,687	1341388
1003763,42	1324123
1313683,82	975089
1475564,7	1213523
551628,19	1348358
671215,9	1743737
412415,54	1981769
381744,833	1352246
787583,66	1230139
243416,025	1308039
68734,181	1340011
71067,916	1378566
276107,687	1368215
1003763,42	1350606
1313683,82	994591
1475564,7	1237793
551628,19	1375326
671215,9	1778611
412415,54	2021404
381744,833	1379291
787583,66	1254741
243416,025	1334199
68734,181	1366811
71067,916	1406138

DEMANDS (m3/s)	
TOTAL	**AGUAS DEL VALLE**
0,39	0,49
0,49	0,35
0,57	0,45
0,21	0,48
0,25	0,63
0,17	0,79
0,14	0,49
0,30	0,46
0,09	0,47
0,03	0,50
0,03	0,49
0,10	0,49
0,39	0,50
0,49	0,36
0,57	0,46
0,21	0,49
0,25	0,64
0,17	0,80
0,14	0,49
0,30	0,47
0,09	0,48
0,03	0,51
0,03	0,50
0,10	0,50
0,39	0,51
0,49	0,36
0,57	0,47
0,21	0,50
0,25	0,65
0,16	0,79
0,14	0,50
0,30	0,47
0,09	0,49
0,03	0,52
0,03	0,51
0,10	0,51
0,39	0,52
0,49	0,37
0,57	0,48
0,21	0,51
0,25	0,66
0,17	0,84
0,14	0,51
0,30	0,48
0,09	0,50
0,03	0,53
0,03	0,52

Año	Mes	"ELQ_B_Culcatan[Cubic Meter]"	"ELQ_B_Callejas"	"AGUAS DEL VALLE[Cubic Meter]"	"ELQ_B_Federico Arcos"	"ELQ_B_Juan Soldado"	"ELQ_B_Particulares"	"ELQ_B_Tejar"	"ELQ_B_Vegas Norte"
2017	8	11058,7	4923,32	1395580	9814,21	195507	9490,32	23547,7	21766,2
2017	9	41315,5	17877,6	1377618	35637,5	709927	34461,4	85506,4	79037,7
2017	10	53672,9	23404,9	1014482	46655,6	929418	45115,8	111943	103474
2017	11	59621,5	26301,3	1262549	52429,5	1044438	50699,2	125796	116279
2017	12	19447,1	9885,33	1402832	19705,6	392551	19055,3	47280,5	43703,5
2018	1	24866	12006	1814184	23933	476765	23143,2	57423,5	53079,2
2018	2	14665,6	7388,22	2061832	14727,9	293391	14241,9	35337,2	32663,8
2018	3	14065,5	6829,68	1406877	13614,4	271210	13165,1	32665,6	30194,4
2018	4	32302	14029,4	1279836	27966,5	557116	27043,6	67101,3	62024,8
2018	5	9907,61	4337,45	1360883	8646,33	172242	8361,01	20745,6	19176,1
2018	6	2807,88	1224,59	1394147	2441,12	48629	2360,55	5857,08	5413,97
2018	7	2900,88	1266,21	1434261	2524,09	50281,8	2440,78	6056,14	5597,98
2018	8	11058,7	4923,32	1423491	9814,21	195507	9490,32	23547,7	21766,2
2018	9	41315,5	17877,6	1405170	35637,5	709927	34461,4	85506,4	79037,7
2018	10	53672,9	23404,9	1034772	46655,6	929418	45115,8	111943	103474
2018	11	59621,5	26301,3	1287800	52429,5	1044438	50699,2	125796	116279
2018	12	19447,1	9885,33	1430889	19705,6	392551	19055,3	47280,5	43703,5
2019	1	24866	12006	1850467	23933	476765	23143,2	57423,5	53079,2
2019	2	14665,6	7388,22	2103069	14727,9	293391	14241,9	35337,2	32663,8
2019	3	14065,5	6829,68	1435015	13614,4	271210	13165,1	32665,6	30194,4
2019	4	32302	14029,4	1305433	27966,5	557116	27043,6	67101,3	62024,8
2019	5	9907,61	4337,45	1388101	8646,33	172242	8361,01	20745,6	19176,1
2019	6	2807,88	1224,59	1422030	2441,12	48629	2360,55	5857,08	5413,97
2019	7	2900,88	1266,21	1462946	2524,09	50281,8	2440,78	6056,14	5597,98
2019	8	11058,7	4923,32	1451961	9814,21	195507	9490,32	23547,7	21766,2
2019	9	41315,5	17877,6	1433274	35637,5	709927	34461,4	85506,4	79037,7
2019	10	53672,9	23404,9	1055468	46655,6	929418	45115,8	111943	103474
2019	11	59621,5	26301,3	1313556	52429,5	1044438	50699,2	125796	116279
2019	12	19447,1	9885,33	1459506	19705,6	392551	19055,3	47280,5	43703,5

DEMANDS (m3/mes)	
TOTAL	**AGUAS DEL VALLE**
276107,687	**1395580**
1003763,42	**1377618**
1313683,82	**1014482**
1475564,7	**1262549**
551628,19	**1402832**
671215,9	**1814184**
412415,54	**2061832**
381744,833	**1406877**
787583,66	**1279836**
243416,025	**1360883**
68734,181	**1394147**
71067,916	**1434261**
276107,687	**1423491**
1003763,42	**1405170**
1313683,82	**1034772**
1475564,7	**1287800**
551628,19	**1430889**
671215,9	**1850467**
412415,54	**2103069**
381744,833	**1435015**
787583,66	**1305433**
243416,025	**1388101**
68734,181	**1422030**
71067,916	**1462946**
276107,687	**1451961**
1003763,42	**1433274**
1313683,82	**1055468**
1475564,7	**1313556**
551628,19	**1459506**

DEMANDS (m3/s)	
TOTAL	**AGUAS DEL VALLE**
0,10	**0,52**
0,39	**0,53**
0,49	**0,38**
0,57	**0,49**
0,21	**0,52**
0,25	**0,68**
0,17	**0,85**
0,14	**0,53**
0,30	**0,49**
0,09	**0,51**
0,03	**0,54**
0,03	**0,54**
0,10	**0,53**
0,39	**0,54**
0,49	**0,39**
0,57	**0,50**
0,21	**0,53**
0,25	**0,69**
0,17	**0,87**
0,14	**0,54**
0,30	**0,50**
0,09	**0,52**
0,03	**0,55**
0,03	**0,55**
0,10	**0,54**
0,39	**0,55**
0,49	**0,39**
0,57	**0,51**
0,21	**0,54**

Appendix C
iMODFLOW output text files
(on request due to its length)

Appendix D
GIRAGUA report (Oct. 2022)

Appendix E
Executable file
Input data generator

```python
import numpy as np
import pandas as pd
import datetime


# -----------------------------------INITIAL STATE CONDITIONS

Puclaro_Init_Volume = [50000000] # m3
Puclaro_Init_Qrelease = [5] # m3/s
Aquifer1_Vol = [400000000] # m3
Aquifer2_Vol = [400000000] # m3
Aquifer3_Vol = [400000000] # m3

ini_state = pd.DataFrame({'storage.V': Puclaro_Init_Volume,
                          'Q_release_reservoir': Puclaro_Init_Qrelease,
                          'Aquifer1.V': Aquifer1_Vol,
                          'Aquifer2.V': Aquifer2_Vol,
                          'Aquifer3.V': Aquifer3_Vol})

ini_state.to_csv(r'C:\Users\garciagr\Test_git\forma\input\initial_state.csv', index=False)


# -----------------------------------TIMESERIES_IMPORT FILE

day = 1
months = 12  #12 months is the minimum
years = 10
total_time = months * years

init_date = []
V_min_Puclaro = []
V_max_Puclaro = []
Q_max_CB = []
Q_max_inf_aq1 = []
Q_max_inf_aq2 = []
Q_max_inf_aq3 = []
Q_ecoMinflow = []
Q_in_reservoir = []
Q_extraction_aquifer1 = []
Q_extraction_aquifer2 = []
Q_extraction_aquifer3 = []



Desmarque = 1
Perc_MinFlow = 0.2
Q_max_CBellavista = 3.67 # m3/s
Q_Max_inf_aq1 = 0.45 # m3/s per aquifer
Q_Max_inf_aq2 = 0.45 # m3/s per aquifer
Q_Max_inf_aq3 = .92 # m3/s per aquifer



for y in range(years):
    for m in range(months):
        init_date = np.append(init_date, datetime.datetime(2010+y, 1+m, day, 0, 0, 0).isoformat(' '))


#----------------Q_in from DGA statistics from Jan-2010 to Dec-2019 (10 years)
Q_DGA = pd.read_excel('C:\\Users\\garciagr\\Test_git\\forma\\Auxiliar\\Q_in_DGA\\Q_in_DGA.xls',
                                  sheet_name='aux', header=0, index_col=0)
for j in range(np.shape(Q_DGA)[0]):
    for m in range(np.shape(Q_DGA)[1]):
        Q_in_reservoir = np.append(Q_in_reservoir, Q_DGA.iloc[j, m])
#---------------------------------------------------------------------------


Q_demands_targets = Desmarque * pd.read_excel('C:\\Users\\garciagr\\Test_git\\forma\\Auxiliar\\FORMA Input analisys.xlsx',
                                  sheet_name='Python_Demands_2010', header=0, index_col=0)

Q_demands_targets['Total'] = Q_demands_targets['D1_m3/s'] + Q_demands_targets['DCB_m3/s'] + Q_demands_targets['D2_m3/s']

Q_ecoMinflow_anual = Perc_MinFlow * np.array([4.93, 4.48, 3.36, 4.49, 5.32, 5.84,
                         9.16, 5.77, 4.08, 2.88, 4.34, 3.84]) #Corresponds to m3/s during the months

V_min_Puclaro_anual = np.array([np.nan, np.nan, np.nan, 50000000, np.nan, np.nan,
                                np.nan, np.nan, np.nan, np.nan, np.nan, np.nan]) #Corresponds to m3 during the months

V_max_Puclaro_anual = np.array([np.nan, np.nan, np.nan, np.nan, np.nan, np.nan,
                                np.nan, 70000000, np.nan, np.nan, np.nan, np.nan]) #Corresponds to m3 during the months

Q_max_CB_anual = np.full(12, Q_max_CBellavista)

Q_max_inf_aq1_anual = np.full(12, Q_Max_inf_aq1)
Q_max_inf_aq2_anual = np.full(12, Q_Max_inf_aq2)
Q_max_inf_aq3_anual = np.full(12, Q_Max_inf_aq3)


#-----------------------iMODFLOW data Extraction----------------------------------------------
ElquiBajo = pd.read_csv('C:\\Users\\garciagr\\Test_git\\forma\\Auxiliar\\ElquiBajo_iMOD.csv', parse_dates=[0], index_col=0)
PanDeAzucar = pd.read_csv('C:\\Users\\garciagr\\Test_git\\forma\\Auxiliar\\PanDeAzucar_iMOD.csv', parse_dates=[0], index_col=0)

#------LOGIC 1: ONLY SOME PACKAGES INCLUDED------LOGIC 1: ONLY SOME PACKAGES INCLUDED------LOGIC 1: ONLY SOME PACKAGES INCLUDED
```

```python
#       LOGIC 1: ONLY SOME PACKAGES INCLUDED       LOGIC 1: ONLY SOME PACKAGES INCLUDED       LOGIC 1: ONLY SOME PACKAGES INCLUDED
# #-----------------------ELQUI BAJO
# ElquiBajo['Extractions'] = ElquiBajo['WEL_SYS7_rate_Out'] + ElquiBajo['WEL_SYS8_rate_Out'] + ElquiBajo['WEL_SYS9_rate_Out']
# ElquiBajo['Recharge'] = ElquiBajo['RCH_SYS1_rate_In'] + ElquiBajo['RCH_SYS2_rate_In'] + \
#                         ElquiBajo['RCH_SYS3_rate_In'] + ElquiBajo['RCH_SYS4_rate_In']

# #-----------------------PAN DE AZUCAR
# PanDeAzucar['Extractions'] = PanDeAzucar['WEL_SYS3_rate_Out']
# PanDeAzucar['Recharge'] = PanDeAzucar['RCH_SYS1_rate_In'] + PanDeAzucar['RCH_SYS2_rate_In'] \
#                         + PanDeAzucar['RCH_SYS3_rate_In'] + PanDeAzucar['RCH_SYS4_rate_In']
# # Precipitations + Irrigation  + Losses in canals with info + Losses in canals without info


#------LOGIC 2: ALL PACKAGES INCLUDED------LOGIC 2: ALL PACKAGES INCLUDED------LOGIC 2: ALL PACKAGES INCLUDED
#-----------------------ELQUI BAJO
ElquiBajo['Lat_recharge'] = ElquiBajo['WEL_SYS2_rate_In'] + ElquiBajo['WEL_SYS3_rate_In'] + ElquiBajo['WEL_SYS4_rate_In'] + \
                            ElquiBajo['WEL_SYS5_rate_In'] + ElquiBajo['WEL_SYS6_rate_In']
ElquiBajo['River_recharge'] = ElquiBajo['RIV_SYS1_rate_In']
ElquiBajo['Nat_Recharge'] = ElquiBajo['RCH_SYS1_rate_In'] + ElquiBajo['RCH_SYS2_rate_In'] + ElquiBajo['RCH_SYS3_rate_In'] + \
                        ElquiBajo['RCH_SYS4_rate_In']
ElquiBajo['Extractions'] = ElquiBajo['WEL_SYS7_rate_Out'] + ElquiBajo['WEL_SYS8_rate_Out'] + ElquiBajo['WEL_SYS9_rate_Out']
ElquiBajo['Drainage'] = ElquiBajo['DRN_SYS1_rate_Out']
ElquiBajo['River_discharge'] = ElquiBajo['RIV_SYS1_rate_Out']
ElquiBajo['Canals_gain'] = ElquiBajo['RCH_SYS3_rate_Out']
ElquiBajo['Recharge'] = ElquiBajo['Lat_recharge'] + ElquiBajo['River_recharge'] + ElquiBajo['Nat_Recharge'] - \
                        ElquiBajo['Drainage'] - ElquiBajo['River_discharge'] - ElquiBajo['Canals_gain']

#-----------------------PAN DE AZUCAR
PanDeAzucar['Lat_recharge'] = PanDeAzucar['GHB_SYS1_rate_In'] + PanDeAzucar['GHB_SYS2_rate_In'] + \
                              PanDeAzucar['GHB_SYS3_rate_In'] + PanDeAzucar['GHB_SYS4_rate_In']
PanDeAzucar['Nat_recharge'] = PanDeAzucar['RCH_SYS1_rate_In'] + PanDeAzucar['RCH_SYS2_rate_In'] + \
                              PanDeAzucar['RCH_SYS3_rate_In'] + PanDeAzucar['RCH_SYS4_rate_In']
PanDeAzucar['Sea_Intrusion'] = PanDeAzucar['CHD_SYS1_rate_In']
PanDeAzucar['Extractions'] = PanDeAzucar['WEL_SYS3_rate_Out']
PanDeAzucar['Drainage'] = PanDeAzucar['DRN_SYS1_rate_Out']
PanDeAzucar['Lat_discharge'] = PanDeAzucar['GHB_SYS1_rate_Out'] + PanDeAzucar['GHB_SYS4_rate_Out']
PanDeAzucar['Sea_discharge'] = PanDeAzucar['CHD_SYS1_rate_Out']
PanDeAzucar['Recharge'] = PanDeAzucar['Lat_recharge'] + PanDeAzucar['Nat_recharge'] + PanDeAzucar['Sea_Intrusion'] -\
                          PanDeAzucar['Drainage'] - PanDeAzucar['Lat_discharge'] - PanDeAzucar['Sea_discharge']

#-----------------------------------------------------------------------------------------------

Q_extraction_aquifer1 = ElquiBajo['Extractions'][0:total_time].values/2 /(24 * 3600)
Q_extraction_aquifer2 = ElquiBajo['Extractions'][0:total_time].values/2 /(24 * 3600)
Q_extraction_aquifer3 = PanDeAzucar['Extractions'][0:total_time].values /(24 * 3600)
Q_Rech_Aq1 = ElquiBajo['Recharge'][0:total_time].values/2 /(24 * 3600)
Q_Rech_Aq2 = ElquiBajo['Recharge'][0:total_time].values/2 /(24 * 3600)
Q_Rech_Aq3 = PanDeAzucar['Recharge'][0:total_time].values /(24 * 3600)
#-----------------------iMODFLOW data Extraction---------------------------------------------

if years > 1:
    for i in range(years):
        Q_ecoMinflow = np.concatenate([Q_ecoMinflow, Q_ecoMinflow_anual])
        V_min_Puclaro = np.concatenate([V_min_Puclaro, V_min_Puclaro_anual])
        V_max_Puclaro = np.concatenate([V_max_Puclaro, V_max_Puclaro_anual])
        Q_max_CB = np.concatenate([Q_max_CB, Q_max_CB_anual])
        Q_max_inf_aq1 = np.concatenate([Q_max_inf_aq1, Q_max_inf_aq1_anual])
        Q_max_inf_aq2 = np.concatenate([Q_max_inf_aq2, Q_max_inf_aq2_anual])
        Q_max_inf_aq3 = np.concatenate([Q_max_inf_aq3, Q_max_inf_aq3_anual])

else:
    Q_ecoMinflow = Q_ecoMinflow_anual
    V_min_Puclaro = V_min_Puclaro_anual
    V_max_Puclaro = V_miax_Puclaro_anual
    Q_max_CB = Q_max_CB_anual
    Q_max_inf_aq1 = Q_max_inf_aq1_anual
    Q_max_inf_aq2 = Q_max_inf_aq2_anual
    Q_max_inf_aq3 = Q_max_inf_aq3_anual


inp_data = pd.DataFrame({'UTC': init_date,
                   'Q_in_reservoir': Q_in_reservoir,
                   'V_min_Puclaro': V_min_Puclaro,
                   'V_max_Puclaro': V_max_Puclaro,
                   'Q_max_CB': Q_max_CB,
                   'Q_max_inf_aq1': Q_max_inf_aq1,
                   'Q_max_inf_aq2': Q_max_inf_aq2,
                   'Q_max_inf_aq3': Q_max_inf_aq3,
                   'Q_extraction_aquifer1': Q_extraction_aquifer1,
                   'Q_extraction_aquifer2': Q_extraction_aquifer2,
                   'Q_extraction_aquifer3': Q_extraction_aquifer3,
                   'Q_demands1_target': Q_demands_targets['D1_m3/s'][0:years*12], # Starts at the 0 row to begin from January
                   'Q_demands2_target': Q_demands_targets['D2_m3/s'][0:years*12],
                   'Q_demands3_target': Q_demands_targets['DCB_m3/s'][0:years*12],
                   'Q_demandsADV_target': Q_demands_targets['DADV_m3/s'][0:years*12],
                   'Q_demands_total_target': Q_demands_targets['Total'][0:years*12],
                   'Q_ecoMinflow': Q_ecoMinflow,
                   'Q_Rech_Aq1': Q_Rech_Aq1,
                   'Q_Rech_Aq2': Q_Rech_Aq2,
                   'Q_Rech_Aq3': Q_Rech_Aq3})

inp_data.to_csv(r'C:\Users\garciagr\Test_git\forma\input\timeseries_import.csv', index=False)
```

```python
print('...')
print('...')
print('Input data generated!')
```

Appendix F
Executable file
FORMA RTC-Tools code

```python
from rtctools.optimization.collocated_integrated_optimization_problem \
    import CollocatedIntegratedOptimizationProblem
from rtctools.optimization.goal_programming_mixin import GoalProgrammingMixin, Goal
from rtctools.optimization.csv_mixin import CSVMixin
from rtctools.optimization.modelica_mixin import ModelicaMixin
from rtctools.util import run_optimization_problem
from rtctools.optimization.timeseries import Timeseries

import numpy as np

# -----------------------START DECLARING GOALS---------------------------------------------------------

class IrrigationDemandsGoal(Goal):
    def __init__(self, optimization_problem, state, target_min, target_max, priority, weight=1.0, order = 1):
        self.priority = priority
        self.order = order
        self.state = state
        self.target_min = target_min
        self.target_max = target_max
        self.weight = weight
        lb, ub = optimization_problem.bounds()[self.state]
        self.function_range = (lb, ub)
    def function(self, optimization_problem, ensemble_member):
        op = optimization_problem
        return op.state(self.state)


class WaterSupplyDemandGoal(Goal):
    def __init__(self, optimization_problem, target_min, target_max, priority, weight=1.0, order = 1):
        self.priority = priority
        self.order = order
        self.demands_ADV = "Q_demandsADV"
        self.target_min = target_min
        self.target_max = target_max
        self.weight = weight
        lb, ub = optimization_problem.bounds()[self.demands_ADV]
        self.function_range = (lb, ub)
    def function(self, optimization_problem, ensemble_member):
        op = optimization_problem
        return op.state(self.demands_ADV)


class MinEcoFLow(Goal):
    def __init__(self, optimization_problem, target_min, priority, weight=1.0, order = 1):
        self.priority = priority
        self.order = order
        self.Riverflow = "Q_river"
        self.target_min = target_min
        self.target_max = np.nan
        self.weight = weight
        lb, ub = optimization_problem.bounds()[self.Riverflow]
        self.function_range = (lb, ub)
    def function(self, optimization_problem, ensemble_member):
        op = optimization_problem
        return op.state(self.Riverflow)

class MinMonthlyVolRes(Goal):
    def __init__(self, optimization_problem, target_min, priority, weight=1.0, order = 1):
        self.priority = priority
        self.order = order
        self.vol = "V_storage"
        self.target_min = target_min
        self.target_max = np.nan
        self.weight = weight
        self.function_nominal = optimization_problem.variable_nominal(self.vol)
        lb, ub = optimization_problem.bounds()[self.vol]
        self.function_range = (lb, ub)
    def function(self, optimization_problem, ensemble_member):
        op = optimization_problem
        return op.state(self.vol)

class MaxMonthlyVolRes(Goal):
    def __init__(self, optimization_problem, target_min, priority, weight=1.0, order = 1):
        self.priority = priority
        self.order = order
        self.vol = "V_storage"
        self.target_min = target_min
        self.target_max = np.nan
        self.weight = weight
        lb, ub = optimization_problem.bounds()[self.vol]
        self.function_range = (lb, ub)
    def function(self, optimization_problem, ensemble_member):
        op = optimization_problem
        return op.state(self.vol)

class MaximizeAquiferInfiltration(Goal):
    # As we want to maximize, we minimize the negative with order 1
    def __init__(self, optimization_problem, priority, weight=1.0, order = 1):
        self.priority = priority
        self.order = order
    def function(self, optimization_problem, ensemble_member):
        op = optimization_problem
#         norm_fact = len(op.times()) * 3
        norm_fact = 1
        return -(op.state("Q_in_aquifer1") + op.state("Q_in_aquifer2") + op.state("Q_in_aquifer3")) / norm_fact


class AquiferDeplitionGoal(Goal):
    # Make sure aquifers are not deplited
    def __init__(self, optimization_problem, state, initial_volume, fraction_of_deplicition, priority, weight=1.0, order = 1):
        self.priority = priority
        self.order = order
        self.state = state
        self.target_min = initial_volume * fraction_of_deplicition
        self.target_max = np.nan
        self.weight = weight
        lb, ub = optimization_problem.bounds()[self.state]
```

```
        lb, ub = optimization_problem.bounds()[self.state]
        self.function_range = (lb, ub)
    def function(self, optimization_problem, ensemble_member):
        op = optimization_problem
        last_timestep = op.times()[-1]
        return op.state_at(self.state, last_timestep)
# # Not really necesary

class PuclaroDeplitionGoal(Goal):
    # Make sure Puclaro Storage is not deplited
    def __init__(self, optimization_problem, state, initial_volume, fraction_of_deplicition, priority, weight=1.0, order = 1):
        self.state = state
        self.target_min = initial_volume * fraction_of_deplicition
        self.target_max = np.nan
        self.priority = priority
        self.order = order
        lb, ub = optimization_problem.bounds()[self.state]
        self.function_range = (lb, ub)
    def function(self, optimization_problem, ensemble_member):
        op = optimization_problem
        last_timestep = op.times()[-1]
        return op.state_at(self.state, last_timestep)


class FairRechargue(Goal):
    # Try to reach a fair recharge between both aquifers
    def __init__(self, optimization_problem, stateAq1, stateAq2, stateAq3, fairness, initial_vol_Aq1, initial_vol_Aq2, initial_vol_Aq3,
                 priority, weight=1.0, order = 1):
        self.stateAq1 = stateAq1
        self.stateAq2 = stateAq2
        self.stateAq3 = stateAq3
        self.fairness = fairness
        self.initial_vol_Aq1 = initial_vol_Aq1
        self.initial_vol_Aq2 = initial_vol_Aq2
        self.initial_vol_Aq3 = initial_vol_Aq3
        self.priority = priority
        self.order = order

    def function(self, optimization_problem, ensemble_member):
        op = optimization_problem
        last_timestep = op.times()[-1]
        funct = (self.initial_vol_Aq1 + self.initial_vol_Aq2) / (op.state_at(self.stateAq1, last_timestep) + op.state_at(self.stateAq2, last_timestep

        return funct ** 2

class MinimizeRateChangeInfiltrating(Goal):
    def __init__(self, optimization_problem, priority, weight=1, order=2):
        self.priority = priority
        self.order = order

    def function(self, optimization_problem, ensemble_member):
        return (optimization_problem.der('Q_in_aquifer1') + optimization_problem.der('Q_in_aquifer2') + optimization_problem.der('Q_in_aquifer3'))


# ------------------------END DECLARING GOALS------------------------------------------------------------


class FORMA(GoalProgrammingMixin, CSVMixin, ModelicaMixin, CollocatedIntegratedOptimizationProblem):
    csv_equidistant = False

# TO_DO'S
# - reservoir minimum discharge rule
# - what is the maximum infiltration rate ?

    def pre(self):
        super().pre()

# ------------------------SURFACE WATER DEMANDS BOUNDARYS------------------------------------------------------------
        # Set bounds of demands discharge
        self._demands_bounds = {}
        self._demands_bounds["Q_demands1"] = (0.0, 50.0) # Q_demands1 is defined as output time series in Modelica
        self._demands_bounds["Q_demands2"] = (0.0, 50.0) # Q_demands2 is defined as output time series in Modelica
        self._demands_bounds["Q_demands3"] = (0.0, 50.0) # Q_demands3 is defined as output time series in Modelica
        self._demands_bounds["Q_demandsADV"] = (0.0, 50.0) # Q_demandsADV is defined as output time series in Modelica
        self._demands_bounds["Q_demands_total"] = (0.0, 200.0) # Q_demands_total is defined as output time series in Modelica
        self.target_demands1 = self.get_timeseries("Q_demands1_target")
        self.target_demands2 = self.get_timeseries("Q_demands2_target")
        self.target_demands3 = self.get_timeseries("Q_demands3_target")
        self.target_demandsADV = self.get_timeseries("Q_demandsADV_target")
        self.target_total_demands = self.get_timeseries("Q_demands_total_target")
        self.min_vol_target = self.get_timeseries("V_min_Puclaro")
        self.max_vol_target = self.get_timeseries("V_max_Puclaro")

# ------------------------AQUIFER INFILTRATION------------------------------------------------------------
        # In the aquifer either the water is extracted or infiltrated
        # As the extraction is, for now, a fixed input we use the information to get the infiltration bounds
        self._aquifer_infiltration_bounds = {}
        times = self.times()
        q_a1_extract = self.get_timeseries("Q_extraction_aquifer1").values
        q_a2_extract = self.get_timeseries("Q_extraction_aquifer2").values
        q_a3_extract = self.get_timeseries("Q_extraction_aquifer3").values

        a1_infiltration_ub = self.get_timeseries("Q_max_inf_aq1").values
        a2_infiltration_ub = self.get_timeseries("Q_max_inf_aq2").values
        a3_infiltration_ub = self.get_timeseries("Q_max_inf_aq3").values

# # ------ Logic 1 ------ for having either infiltration or extraction from the aquifers.
#         a1_infiltration_ub = np.full_like(times, a1_max_infiltration_rate)
#         a1_infiltration_ub[q_a1_extract > 0.0] = 0.0
#         a2_infiltration_ub = np.full_like(times, a2_max_infiltration_rate)
#         a2_infiltration_ub[q_a2_extract > 0.0] = 0.0
#         a3_infiltration_ub = np.full_like(times, a3_max_infiltration_rate)
#         a3_infiltration_ub[q_a3_extract > 0.0] = 0.0
#         self._aquifer_infiltration_bounds["Q_in_aquifer1"] = (0.0, Timeseries(times, a1_infiltration_ub))
#         self._aquifer_infiltration_bounds["Q_in_aquifer2"] = (0.0, Timeseries(times, a2_infiltration_ub))
#         self._aquifer_infiltration_bounds["Q_in_aquifer3"] = (0.0, Timeseries(times, a3_infiltration_ub))

# -------- Logic 2 ------ for having free infiltration to the aquifers
```

```
#         Logic 2        for having free infiltration to the aquifers.
#         a1_infiltration_ub = np.full_like(times, a1_max_infiltration_rate)
#         a2_infiltration_ub = np.full_like(times, a2_max_infiltration_rate)
#         a3_infiltration_ub = np.full_like(times, a3_max_infiltration_rate)
        self._aquifer_infiltration_bounds["Q_in_aquifer1"] = (0.0, Timeseries(times, a1_infiltration_ub))
        self._aquifer_infiltration_bounds["Q_in_aquifer2"] = (0.0, Timeseries(times, a2_infiltration_ub))
        self._aquifer_infiltration_bounds["Q_in_aquifer3"] = (0.0, Timeseries(times, a3_infiltration_ub))

#-----------------------ECOLOGICAL MINIMUM FLOW IN THE RIVER-------------------------------------------

# # ------ Logic 1 ------ for Ecological Flow as a BOUNDRY.
#     # minimum flow for the river: In timeseries. (to keep in mind:this bound can also be a goal)
#         self._q_ecoMinflow = self.get_timeseries("Q_ecoMinflow").values
#         self._river_discharge_bounds = {}
#         self._river_discharge_bounds["Q_river"] = (Timeseries(times, self._q_ecoMinflow), Timeseries(times, self._q_ecoMinflow)) # Q_river is define

# -------- Logic 2 ----- for Ecological Flow as a GOAL.
#       Set bounds of River discharge
        self._river_discharge_bounds = {}
        self._river_discharge_bounds["Q_river"] = (0.0, 100.0) # Q_river is defined as output time series in Modelica
        self.q_ecoMinflow = self.get_timeseries("Q_ecoMinflow")

#-----------------------CANAL BELLAVISTA MAXIMUM FLOW CAPACITY------------------------------------------

        self._Q_CB_bounds = {}
        self._Qmax_CB = self.get_timeseries("Q_max_CB").values
        self._Q_CB_bounds["Q_CB"] = (0, Timeseries(times, self._Qmax_CB)) # Q_CB is defined in Modelica

# ---------------------------------------------------------------------------------------------------

    def bounds(self):
        bounds = super().bounds()
        bounds.update(self._demands_bounds)
        bounds.update(self._aquifer_infiltration_bounds)
        bounds.update(self._river_discharge_bounds) # This works for Logic 1 and Logic 2 of the Ecological Flow
        bounds.update(self._Q_CB_bounds)
        return bounds


    def path_goals(self):
        goals = super().path_goals()

        # GOAL 1------------- Meet the water supply demands
        goals.append(WaterSupplyDemandGoal(self, target_min=self.target_demandsADV, target_max=self.target_demandsADV, priority=10))

        # GOAL 2------------- Try to reach the Ecological flow
        goals.append(MinEcoFLow(self, target_min=self.q_ecoMinflow, priority=20))

        # GOAL 3------------- Minimum volume reservoir for END of season (August)
        goals.append(MinMonthlyVolRes(self, target_min=self.min_vol_target, priority=30, order=1))

        # GOAL 5------------- Try to meet the irrigation demands
        for d in ['demands1', 'demands2', 'demands3']:
            target = self.get_timeseries("Q_"+ d + "_target")
            state_name = 'Q_'+ d
            goals.append(IrrigationDemandsGoal(self, state=state_name, target_min=target, target_max=target, priority=50))

        # GOAL 7------------- Maximize infiltration
        goals.append(MaximizeAquiferInfiltration(self, priority=70))

        # GOAL 6------------- Minimize Rate of change on aquifer infiltration
        goals.append(MinimizeRateChangeInfiltrating(self, priority=60))

        return goals


    def goals(self):
        goals = super().goals()
        history = self.history(0)

        # GOAL 4------------- Try not depliting the Puclaro Storage at the end of the run
        initial_Puclaro_volume_val = history["V_storage"].values[0]
        goals.append(PuclaroDeplitionGoal(self, state="V_storage", initial_volume=initial_Puclaro_volume_val, fraction_of_deplicition=1, priority=40)

        # GOAL 8------------- Try not depliting the aquifers at the end of the run
        for aquifer in ["aquifer1"]:
            v_aquifer = "V_"+aquifer
            initial_volume_val = history[v_aquifer].values[0]
            goals.append(AquiferDeplitionGoal(self, state=v_aquifer, initial_volume=initial_volume_val, fraction_of_deplicition=1, priority=80))

         # GOAL 9------------- Fairness on the Aquifers artificial recharge
        initial_Aq1_volume_val = history["V_aquifer1"].values[0]
        initial_Aq2_volume_val = history["V_aquifer2"].values[0]
        initial_Aq3_volume_val = history["V_aquifer3"].values[0]
        goals.append(FairRechargue(self, stateAq1="V_aquifer1", stateAq2="V_aquifer2", stateAq3="V_aquifer3", fairness=1, initial_vol_Aq1=initial_Aq1_

        return goals

# HAVE TO DECIDE IF THE FINAL VOLUME OF AQUIFER IS GOING TO BE A GOAL OR A CONSTRAIN

#     def constraints(self, ensemble_member):
#         constraints = super().constraints(ensemble_member)

#         # TMP: the aquifers should not be emptied at the end of the run
#         # Make sure the total volume of the aquifers at the end of the run is at least 75% of what it was at the beginning
#         history = self.history(0)
#         last_timesteps = self.times()[-1]
#         initial_volume_aquifers = history["V_aquifer1"].values[0] + history["V_aquifer2"].values[0]

#         constraints.append((
#             self.state_at("V_aquifer1", last_timesteps) + self.state_at("V_aquifer2", last_timesteps), initial_volume_aquifers * 0.75, np.inf
#             ))
#         return constraints

    def goal_programming_options(self):
        options = super().goal_programming_options()
        options['keep_soft_constraints'] = True
        options['constraint_relaxation'] = 1E-4
```

```
        return options

    def post(self):
        super().post()
        results = self.extract_results()

# Run
run_optimization_problem(FORMA)

import Report
```

Appendix G
Executable file
Report code

```python
import numpy as np
import pandas as pd

Results = pd.read_csv('C:\\Users\\garciagr\\Test_git\\forma\\output\\timeseries_export.csv', parse_dates=[0], index_col=0)
Inputs = pd.read_csv('C:\\Users\\garciagr\\Test_git\\forma\\input\\timeseries_import.csv', parse_dates=[0], index_col=0)

Goal_WaterSupply = Results['Q_demandsADV'].sum() / Inputs['Q_demandsADV_target'].sum() *100
Goal_EcoFLow = Results['Q_river'].sum() / Inputs['Q_ecoMinflow'].sum() *100
Goal_IrrigDemands = Results['Q_demands_total'].sum() / Inputs['Q_demands_total_target'].sum() *100

Elqui_init = Results['V_aquifer1'][0] + Results['V_aquifer2'][0]
Elqui_var = (Results['V_aquifer1'][-1] + Results['V_aquifer2'][-1] - Elqui_init) / Elqui_init * 100
PanAz_var = (Results['V_aquifer3'][-1] - Results['V_aquifer3'][0]) / Results['V_aquifer3'][0] * 100
Aq_init = Results['V_aquifer1'][0] + Results['V_aquifer2'][0] + Results['V_aquifer3'][0]
Aq_var = (Results['V_aquifer1'][-1] + Results['V_aquifer2'][-1] + Results['V_aquifer3'][-1] - Aq_init) / Aq_init * 100


#Time steps that demands are smallers that Puclaro realese discharge
count = 0
for i in range(Results.shape[0]):
    Tot_demand = Inputs['Q_demands_total_target'][i] + Inputs['Q_demandsADV_target'][i] + Inputs['Q_ecoMinflow'][i]
    Puc_release = Results['Q_release_reservoir'][i]
    dif = Puc_release - Tot_demand
    if dif >= 0:
        count += 1
Puc_goal = count / Results.shape[0] * 100


# Number of months that volume increase respect lasth months / Total number of month
Elqui_aq_vol = Results.V_aquifer1 + Results.V_aquifer2
Tot_aq_vol = Results.V_aquifer1 + Results.V_aquifer2 + Results.V_aquifer3
n_increase_Aq1y2, n_increase_Aq3, n_increase_AqTot = 0, 0, 0
for i in range(len(Results.V_aquifer1)-1):
    if Elqui_aq_vol[i] < Elqui_aq_vol[i+1]:
        n_increase_Aq1y2 +=1
    if Results.V_aquifer3[i] < Results.V_aquifer3[i+1]:
        n_increase_Aq3 +=1
    if Tot_aq_vol[i] < Tot_aq_vol[i+1]:
        n_increase_AqTot +=1
Month_incr_Elqui = n_increase_Aq1y2 / (len(Results.V_aquifer1)-1) * 100
Month_incr_PdA = n_increase_Aq3 / (len(Results.V_aquifer1)-1) * 100
Month_incr_Tot = n_increase_AqTot / (len(Results.V_aquifer1)-1) * 100


#IEAS index (Indice de Explotacion Aquiferos)
Tot_extr = Inputs['Q_extraction_aquifer1'] + Inputs['Q_extraction_aquifer2'] + Inputs['Q_extraction_aquifer3']
Tot_rech = Inputs['Q_Rech_Aq1'] + Inputs['Q_Rech_Aq2'] + Inputs['Q_Rech_Aq3']
Elqui_infilt = Results['Q_in_aquifer1'] + Results['Q_in_aquifer2']
Tot_infilt = Results['Q_in_aquifer1'] + Results['Q_in_aquifer2'] + Results['Q_in_aquifer3']

#Not including artificial recharge
IEASn_Elqui = (Inputs['Q_extraction_aquifer1'].sum() + Inputs['Q_extraction_aquifer2'].sum()) / \
              (Inputs['Q_Rech_Aq1'].sum() + Inputs['Q_Rech_Aq1'].sum())
IEASn_PdA = Inputs['Q_extraction_aquifer3'].sum() / Inputs['Q_Rech_Aq3'].sum()
IEASn_Tot = Tot_extr.sum() / Tot_rech.sum()

#Including artificial recharge
IEASr_Elqui = (Inputs['Q_extraction_aquifer1'].sum() + Inputs['Q_extraction_aquifer2'].sum()) / \
              (Inputs['Q_Rech_Aq1'].sum() + Inputs['Q_Rech_Aq1'].sum() + Elqui_infilt.sum())
IEASr_PdA = Inputs['Q_extraction_aquifer3'].sum() / (Inputs['Q_Rech_Aq3'].sum() + Results['Q_in_aquifer3'].sum())
IEASr_Tot = Tot_extr.sum() / (Tot_rech.sum() + Tot_infilt.sum())


print('')
print('GOALS RESULTS:')
print(f'Average % of Water supply Goal:                          {Goal_WaterSupply:.2f} %')
print(f'Average % of Ecological minimum flow Goal:               {Goal_EcoFLow:.2f} %')
print(f'Average % of Irrigation demands Goal:                    {Goal_IrrigDemands:.2f} %')
print('')
print('AQUIFER RESULTS:')
print('Elqui aquifer:')
print(f'Change % on Elqui Aquifer:                               {Elqui_var:.2f} %')
print(f'% of months that Elqui aquifer volume increase:          {Month_incr_Elqui:.2f} %')
print(f'IEAS index:                                              {IEASn_Elqui:.2f}')
print(f'IEAS index with infiltration:                            {IEASr_Elqui:.2f}')
print('')
print('Pan de Azucar aquifer:')
print(f'Change % on Pan de Azucar Aquifer:                       {PanAz_var:.2f} %')
print(f'% of months that Pan de Azucar aquifer volume increase: {Month_incr_PdA:.2f} %')
print(f'IEAS index:                                              {IEASn_PdA:.2f}')
print(f'IEAS index with infiltration:                            {IEASr_PdA:.2f}')
print('')
print('Total aquifers:')
print(f'Change % on Aquifers:                                    {Aq_var:.2f} %')
print(f'% of months that Total aquifers volume increase:         {Month_incr_Tot:.2f} %')
print(f'IEAS index:                                              {IEASn_Tot:.2f}')
print(f'IEAS index with infiltration:                            {IEASr_Tot:.2f}')
print('')
```

```
print('')
print('PUCLARO RESULTS:')
print(f'Timesteps % that the Puclaro release meet demands:      {Puc_goal:.2f} %')
```

Appendix H
Sensibility analysis

Sensitivity analysis in terms of different input values

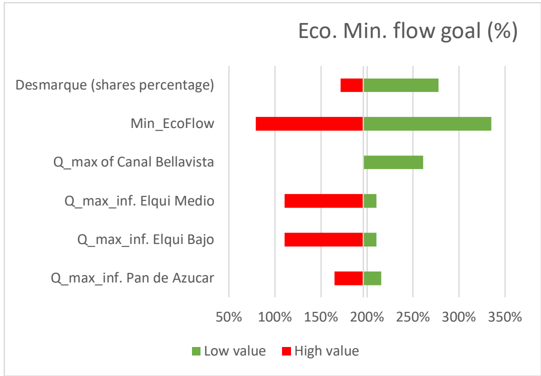
Input	Base input	Low range	High range
Desmarque (shares percentage)	1,00	0,475	1,20
Min_EcoFlow (%)	0,20	0,10	1,00
Q_max of Canal Bellavista (m3/s)	3,67	1,00	4,04
Q_max_inf. Elqui Medio (m3/s)	0,45	0,10	10,00
Q_max_inf. Elqui Bajo (m3/s)	0,45	0,10	10,00
Q_max_inf. Pan de Azucar (m3/s)	0,92	0,46	3,67

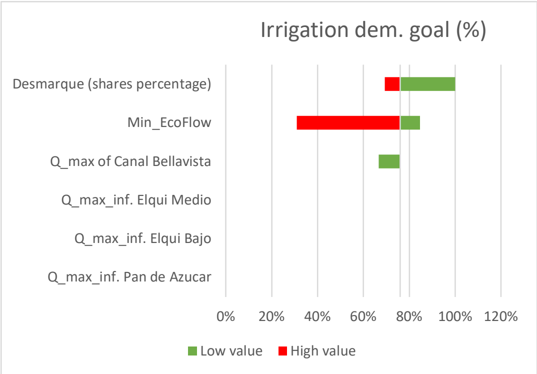
Description		
Base input	**Low range**	**High range**
Total potential demand for irrigation.	Average desmarque (47,5 %)	Increase of the irrigation potential
20 % of the Environmental Reserve	10 % of the Environmental Reserve	Environmental Reserve
Actual capacity based in acciones	-	Increase of 10%
Scenario B of Giragua (0,90 m3/s)	Scenario A of Giragua (0,20 m3/s)	No restriction
Giragua max inf. Disch. (0,92 m3/s)	Giragua average inf. Disch. (0,46 m3/s)	100 % of CB capacity (3,67 m3/s)

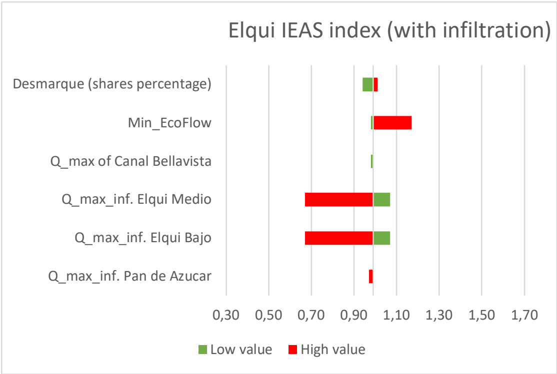
Model results	Base values
GOAL Results	
Drinking water supply goal (%)	**100,00%**
Ecological minimum flow goal (%)	**195,82%**
Irrigation demands goal (%)	**76,03%**
AQUIFER Results	
Elqui Aquifer	
Change % Elqui aquifer	**1,01%**
% of months that volume increase:	**45,38%**
IEAS index	**1,24**
IEAS index with infiltration	**0,99**
Pan de Azucar aquifer	
Change % Pan de Azucar aquifer	**-14,61%**
% of months that volume increase:	**32,77%**
IEAS index	**1,70**
IEAS index with infiltration	**1,14**
Total aquifer	
Change % on aquifers	**-4,20%**
% of months that volume increase:	**41,18%**
IEAS index	**1,41**
IEAS index with infiltration	**1,05**
PUCLARO Results	
Timesteps that releases meet demands	**58,33%**

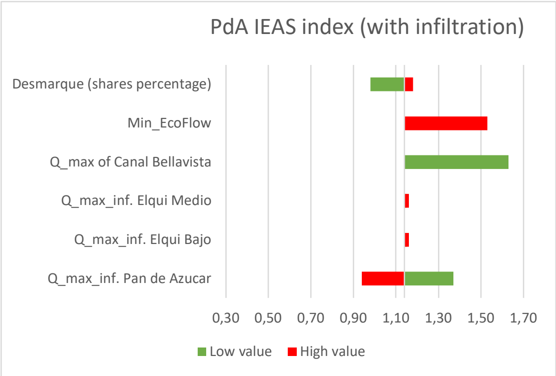
Sensitivity analysis in terms of different input values

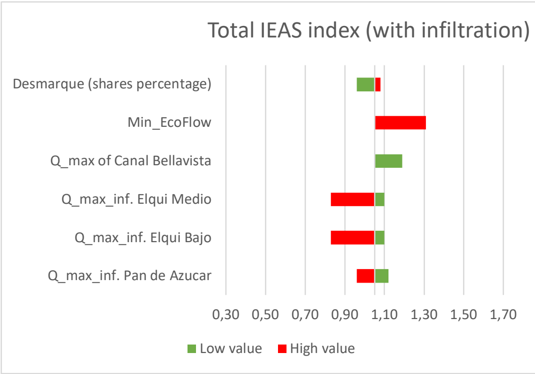
Input	Eco. Min. flow goal (%)		Irrigation dem. goal (%)		Elqui IEAS with inf.		PdA IEAS with inf.		Total IEAS with inf.	
	Low value	High value	Low value	High value	Low value	High value	Low value	High value	Low value	High value
Desmarque (shares percentage)	277,64%	171,40%	100,00%	69,40%	0,94	1,01	0,98	1,18	0,96	1,08
Min_EcoFlow	334,92%	79,36%	84,68%	30,92%	0,98	1,17	1,14	1,53	1,05	1,31
Q_max of Canal Bellavista	261,03%	195,81%	66,66%	76,03%	0,98	0,99	1,63	1,14	1,19	1,05
Q_max_inf. Elqui Medio	210,25%	110,57%	76,03%	76,03%	1,07	0,67	1,15	1,16	1,10	0,83
Q_max_inf. Elqui Bajo	210,28%	110,57%	76,03%	76,03%	1,07	0,67	1,15	1,16	1,10	0,83
Q_max_inf. Pan de Azucar	215,17%	164,45%	76,03%	76,03%	0,98	0,97	1,37	0,94	1,12	0,96





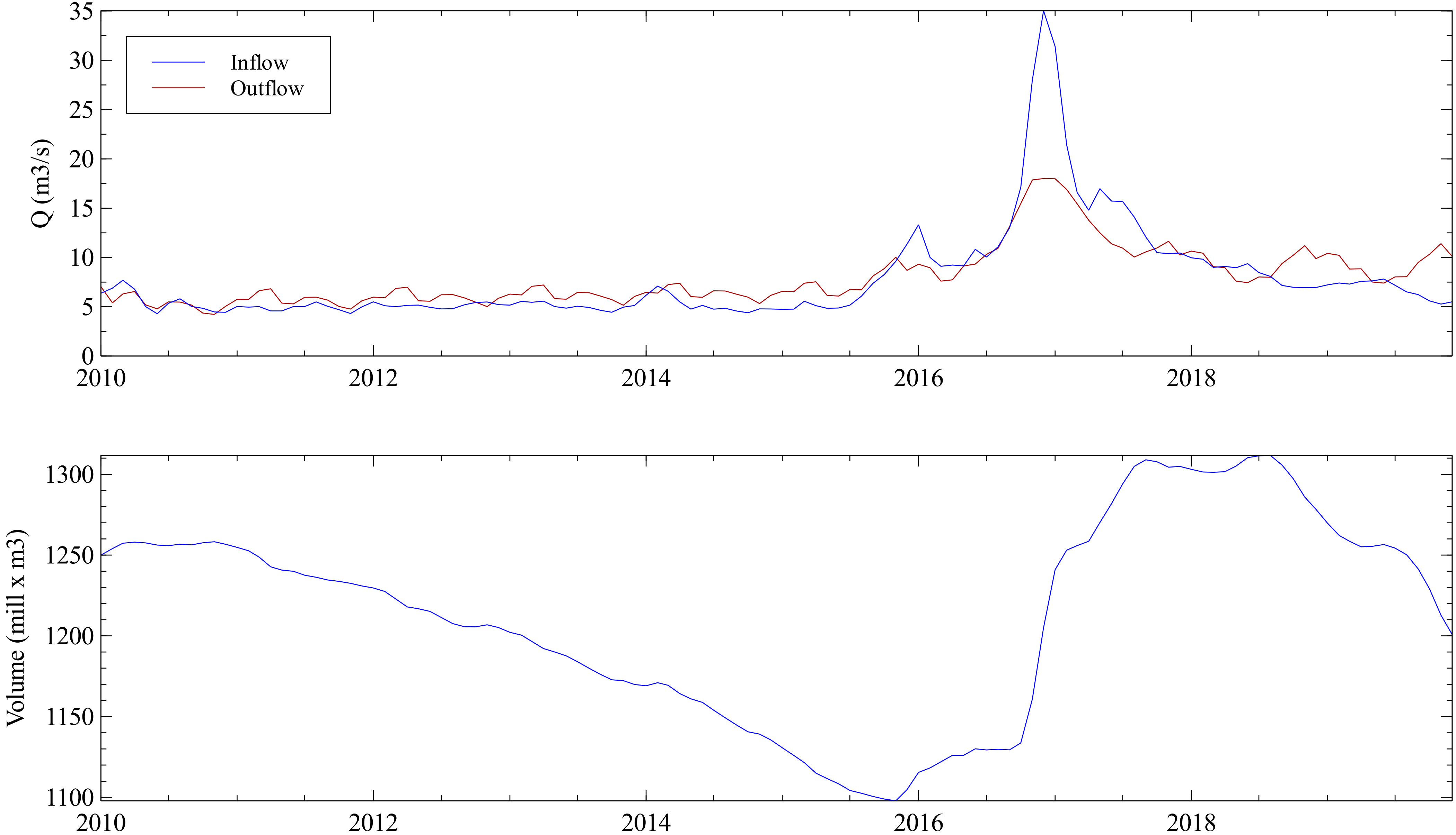




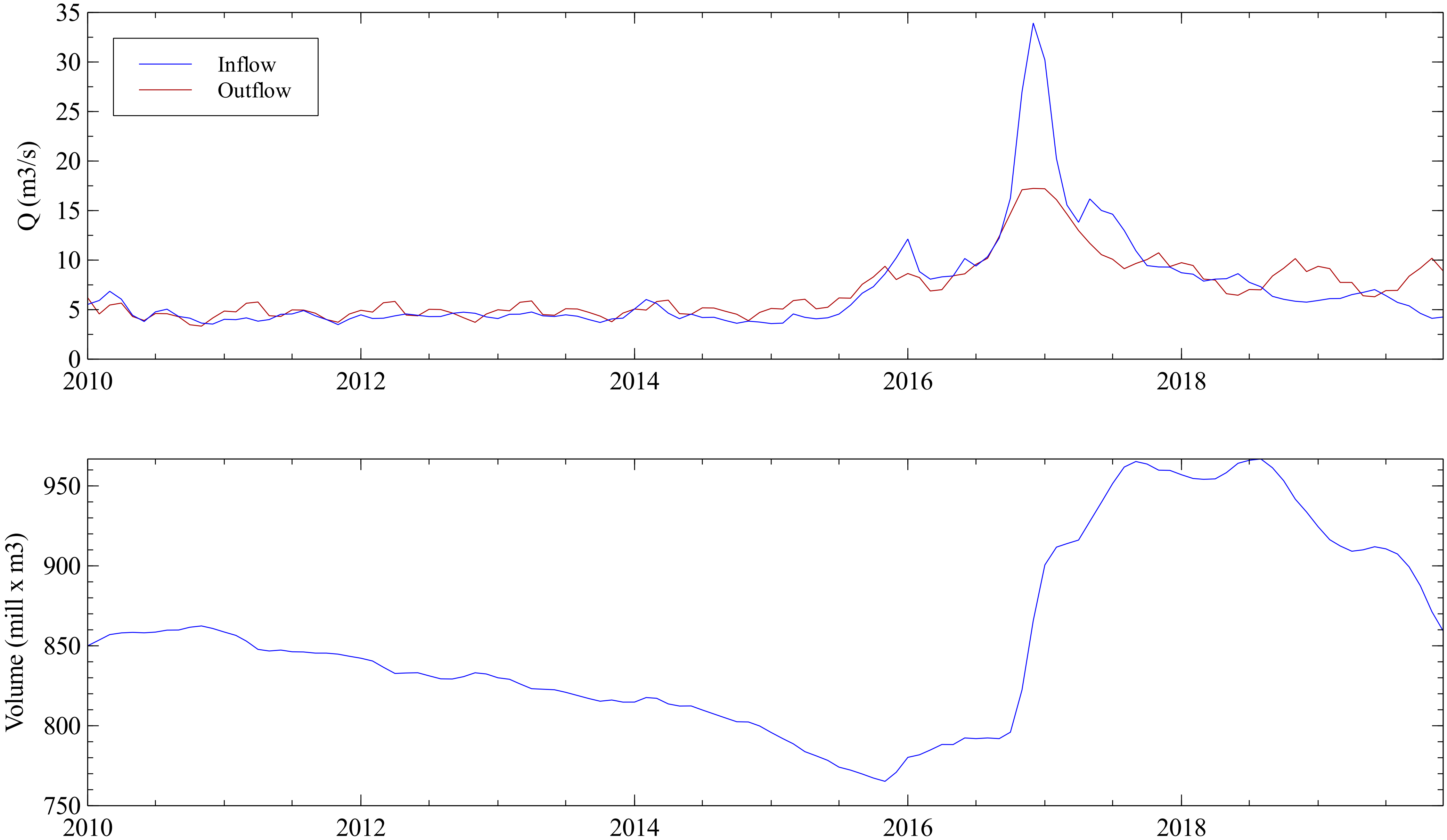


Appendix I
Reference Case

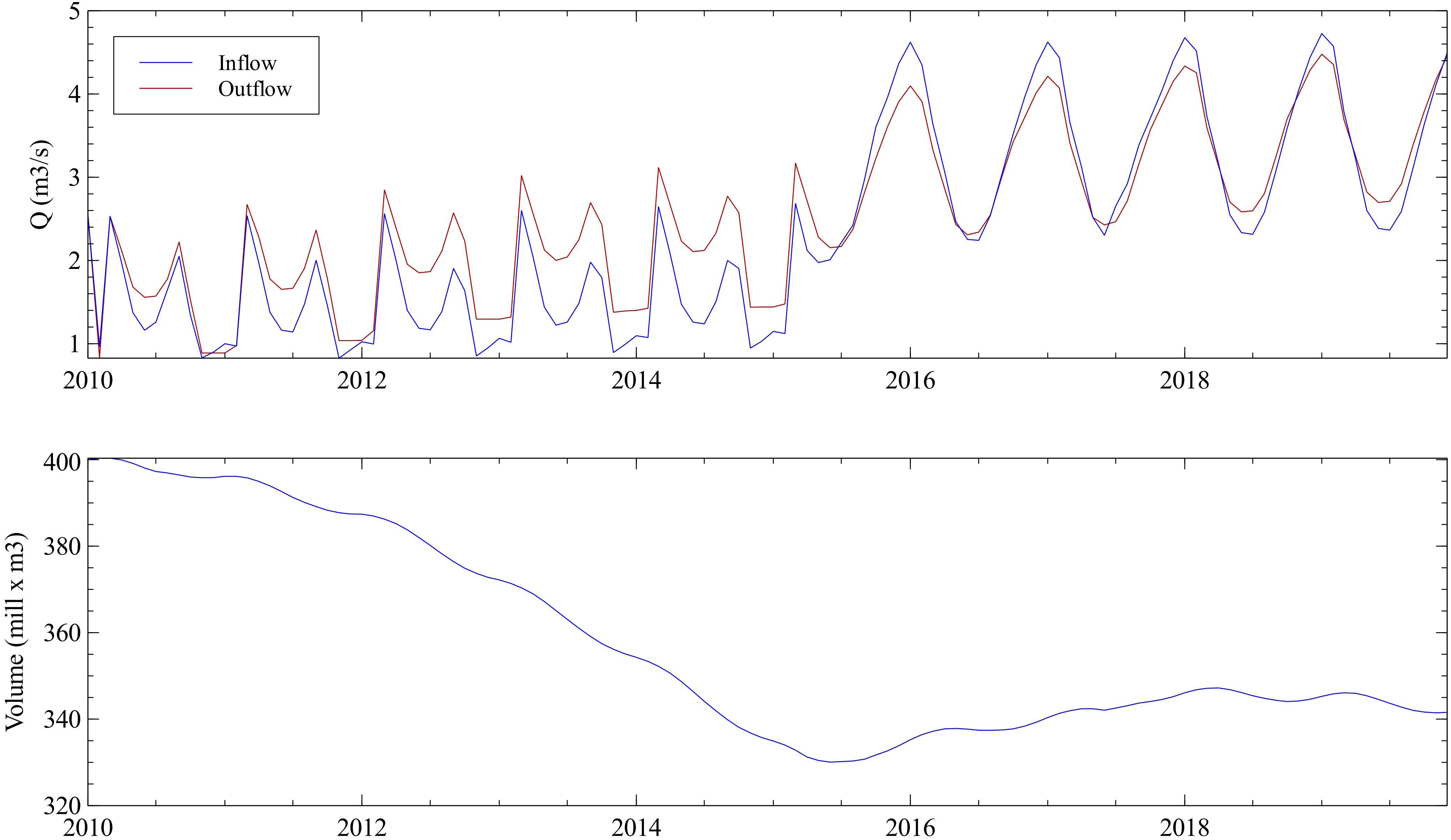
Total water balance

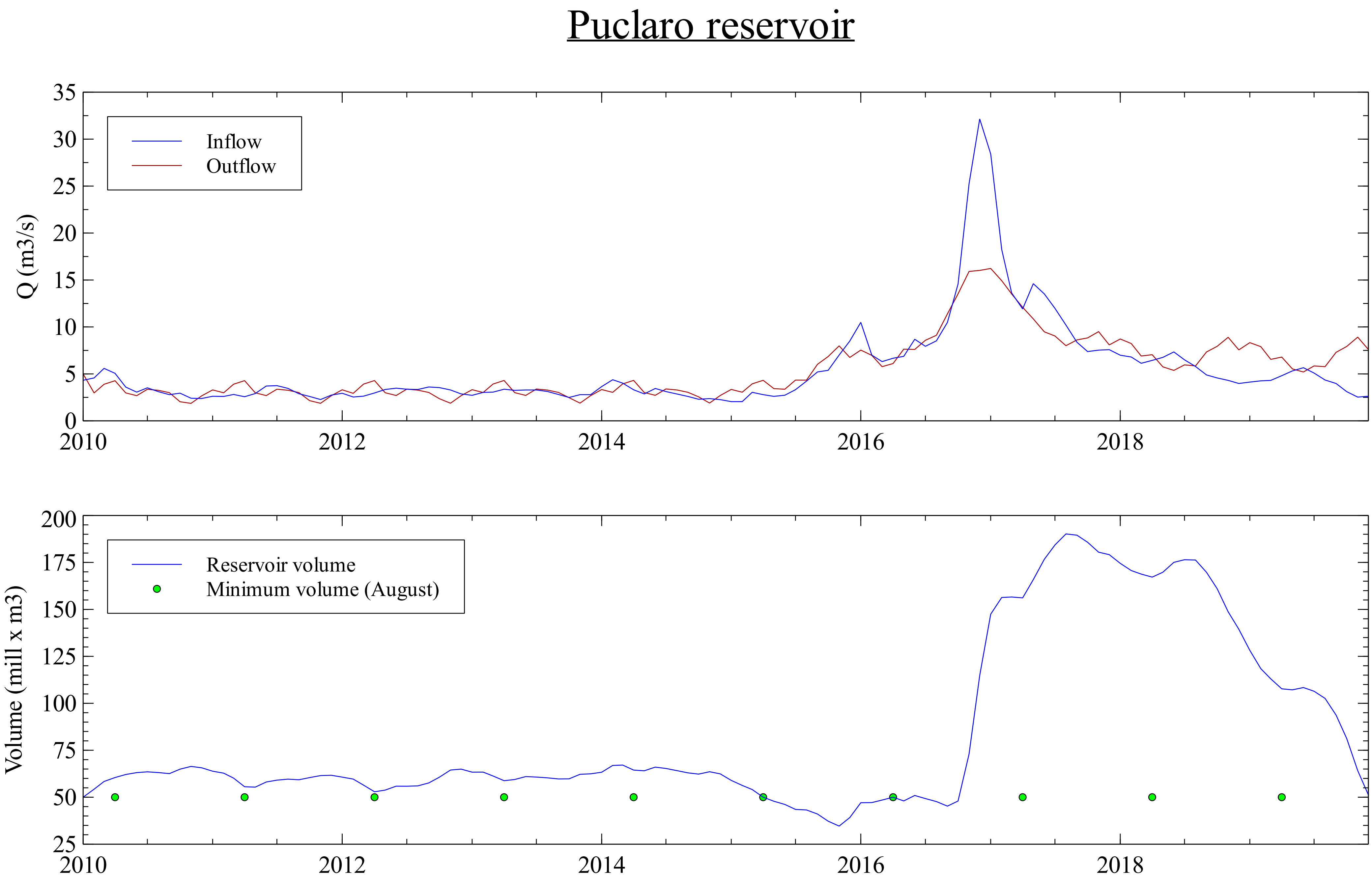


Elqui water balance

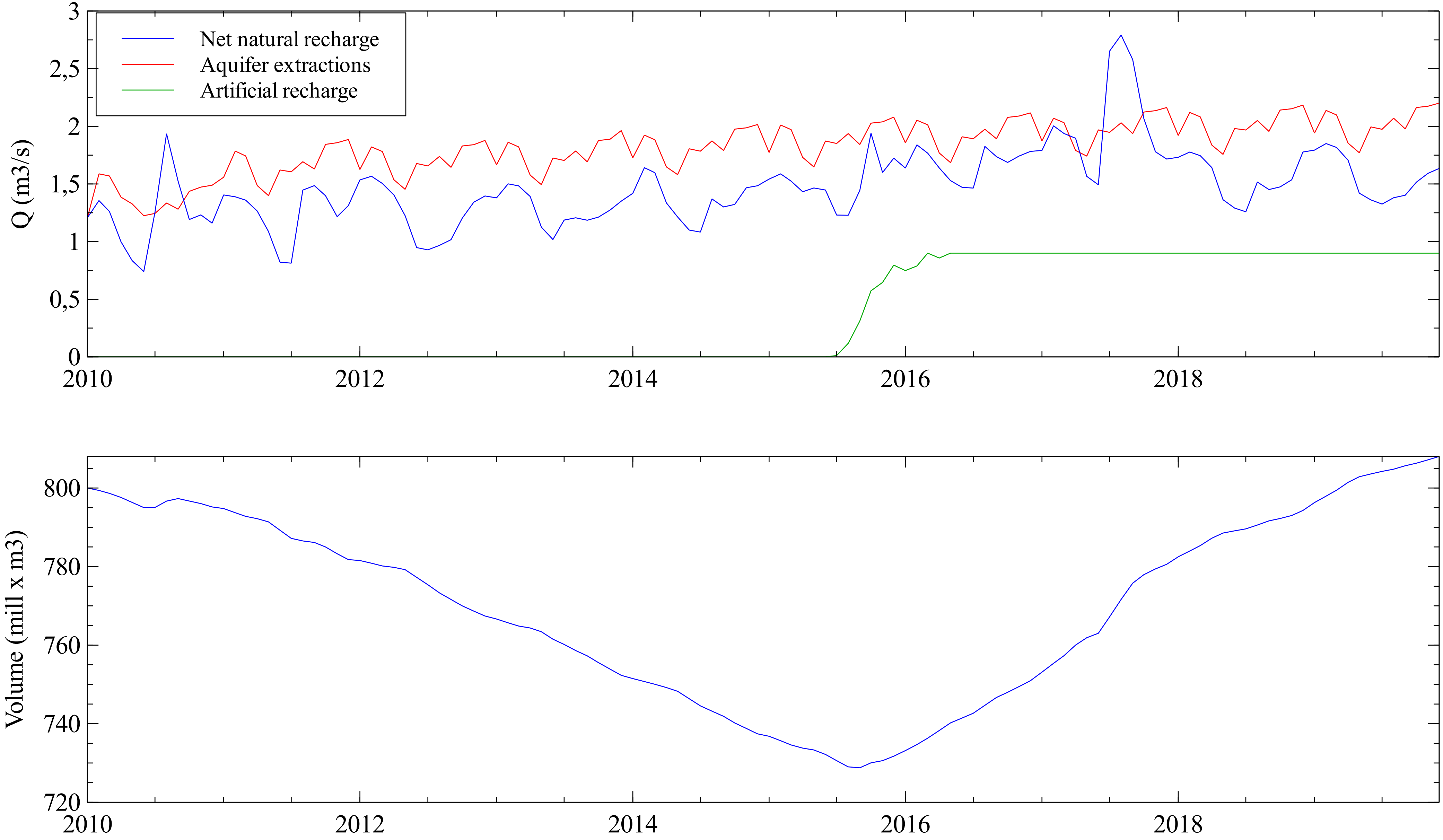


Pan de Azúcar water balance

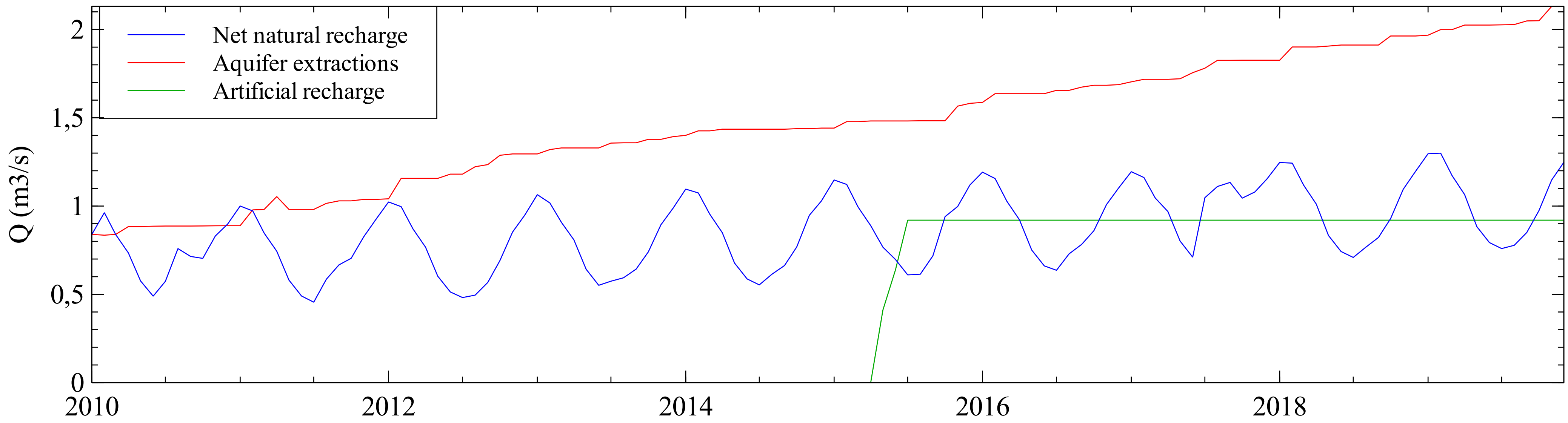


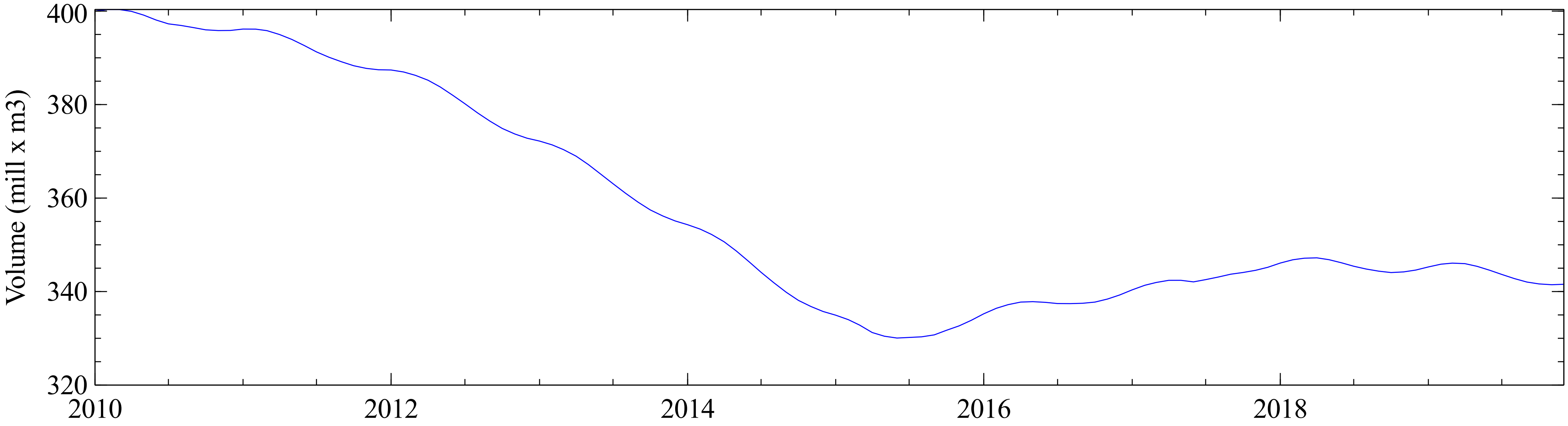

Puclaro reservoir
Q (m3/s)
35
30
25
20
15
10
5
0
Inflow
Outflow
2010
2012
2014
2016
2018
Volume (mill x m3)
200
175
150
125
100
75
50
25
Reservoir volume
Minimum volume (August)
2010
2012
2014
2016
2018

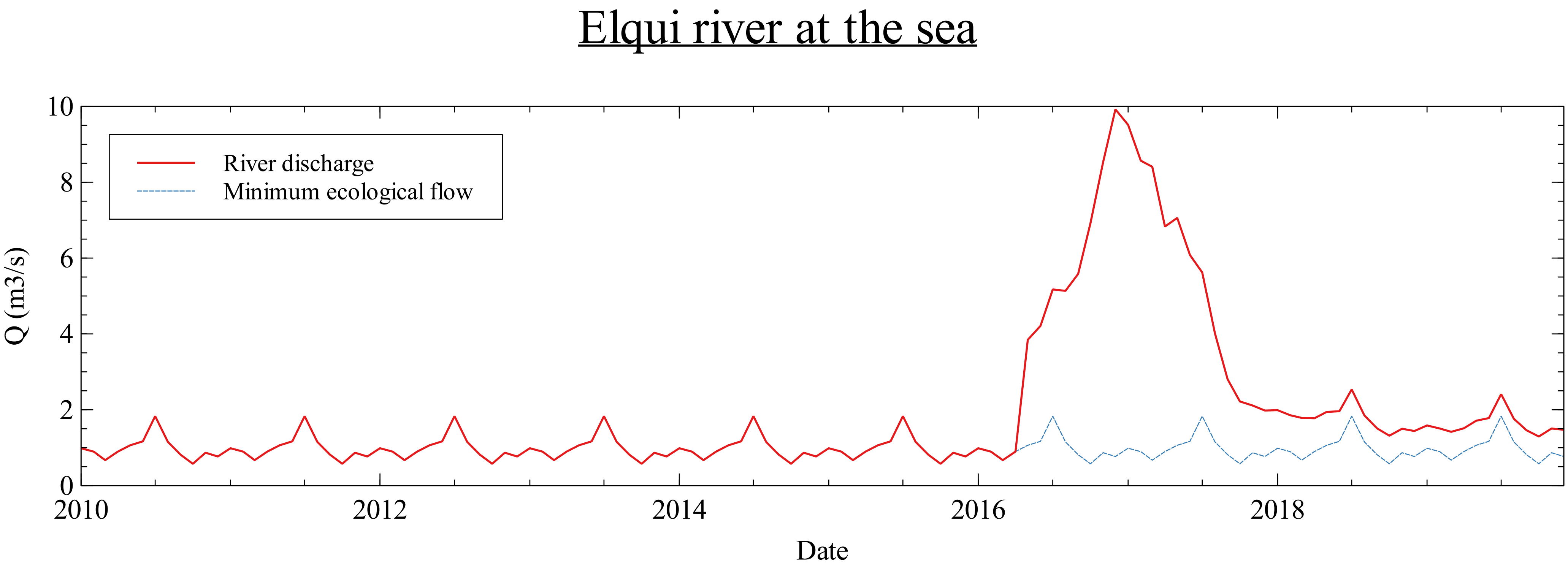
Elqui aquifer



Pan de Azúcar aquifer

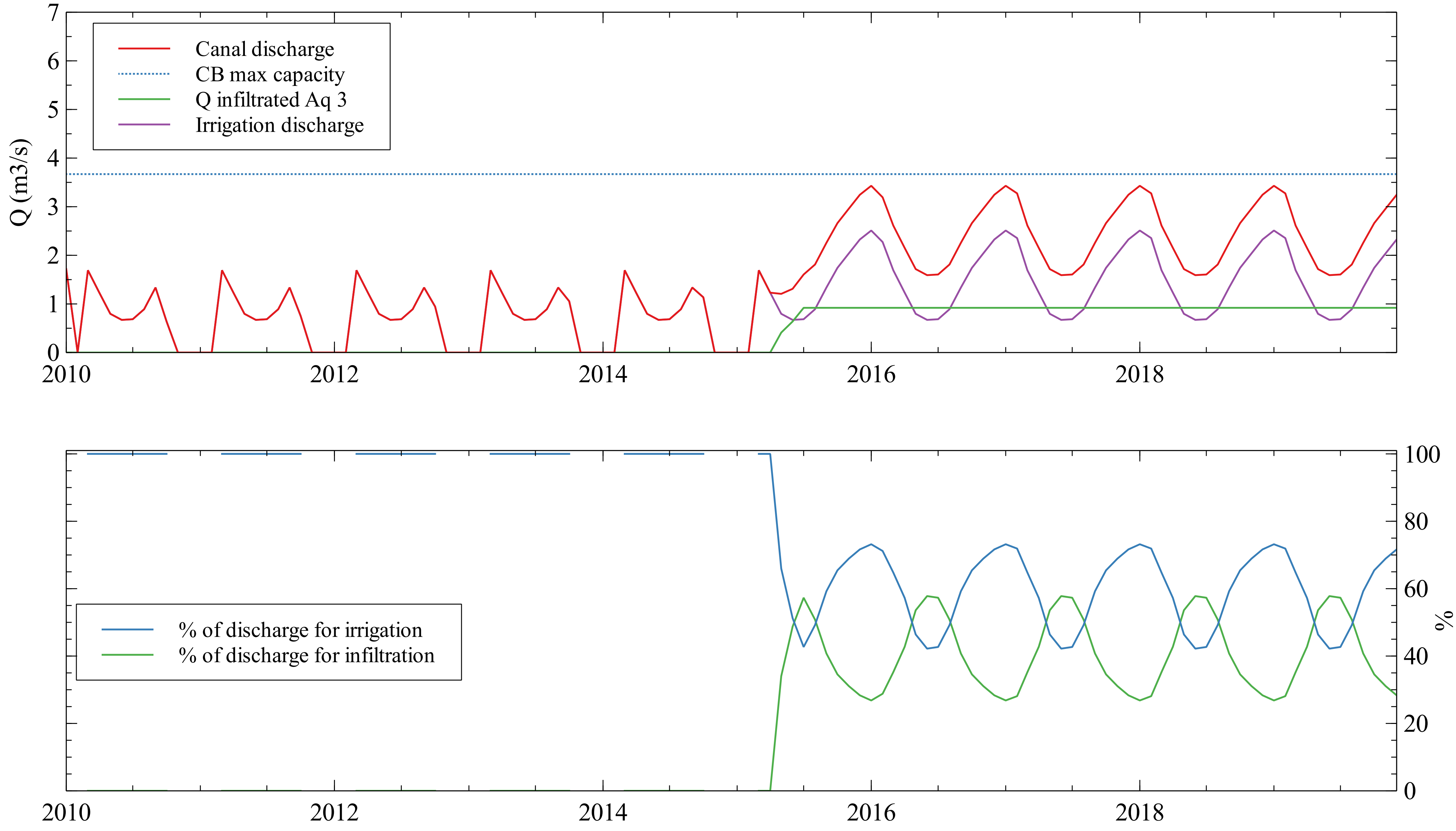




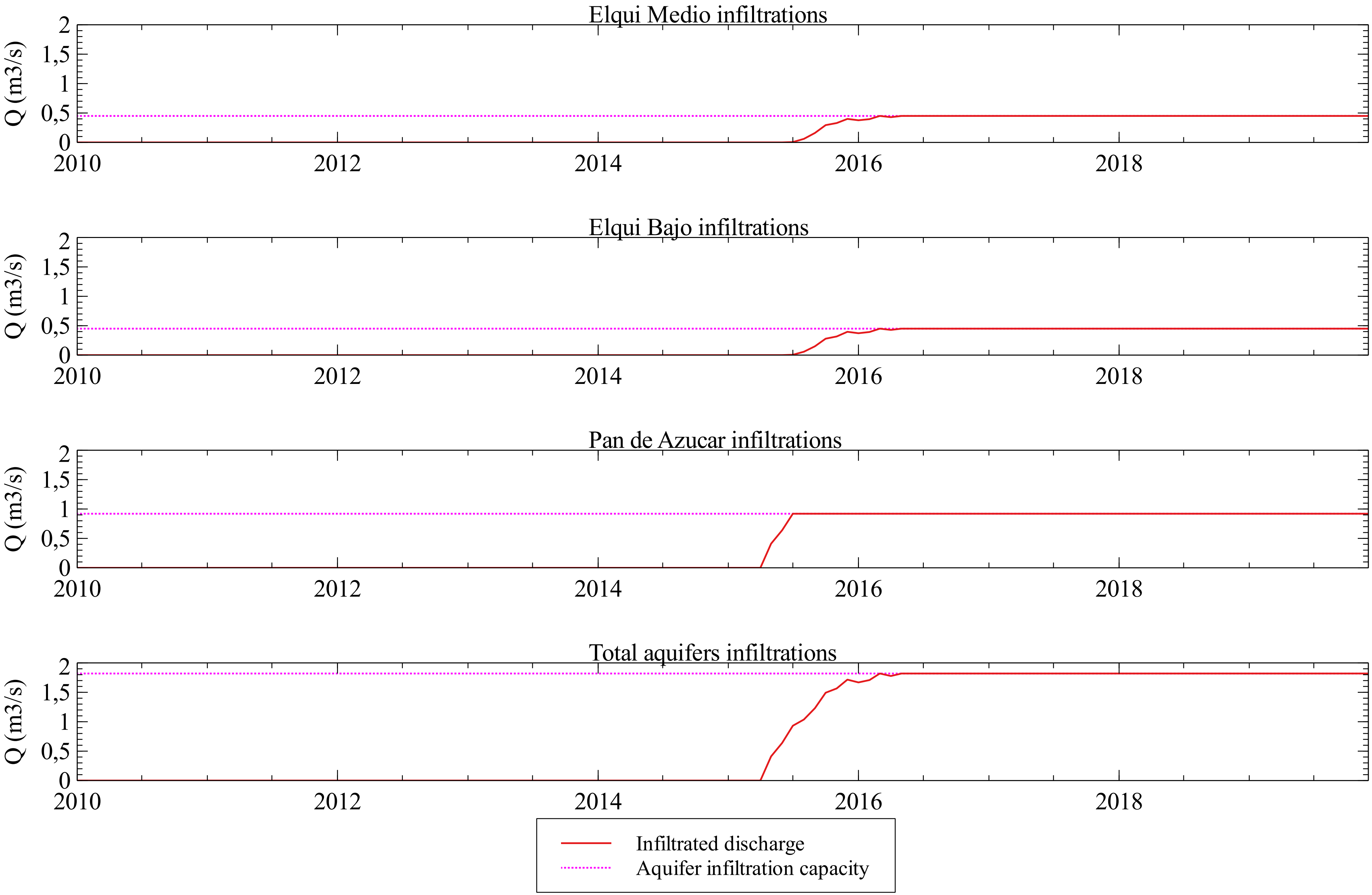


Elqui river at the sea
River discharge
Minimum ecological flow
Q (m3/s)
0
2
4
6
8
10
2010
2012
2014
2016
2018
Date

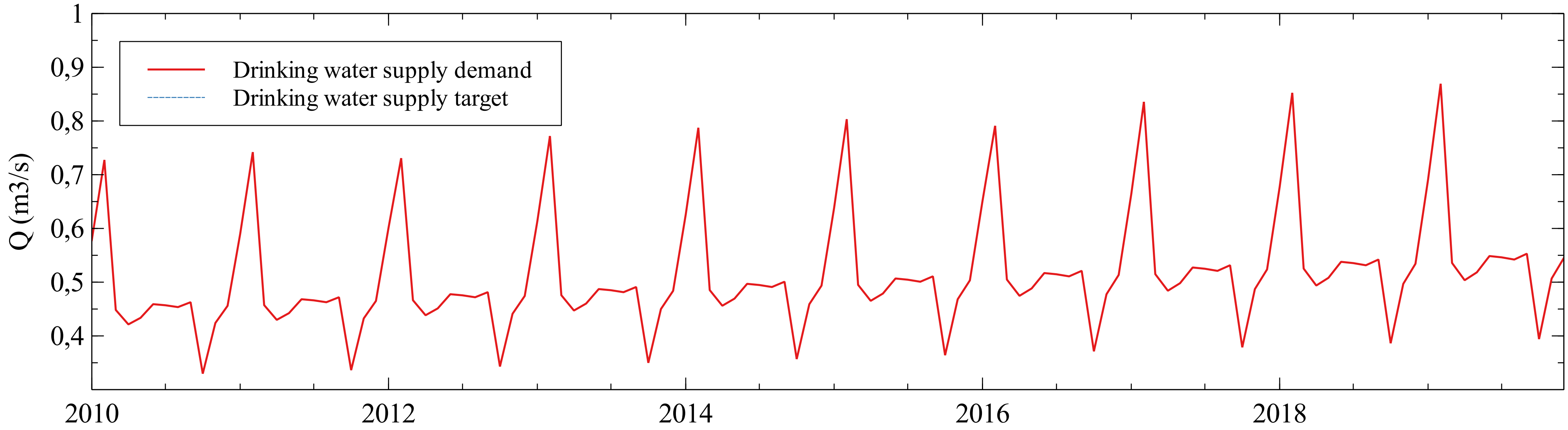
Canal Bellavista



Artificial infiltration analysis

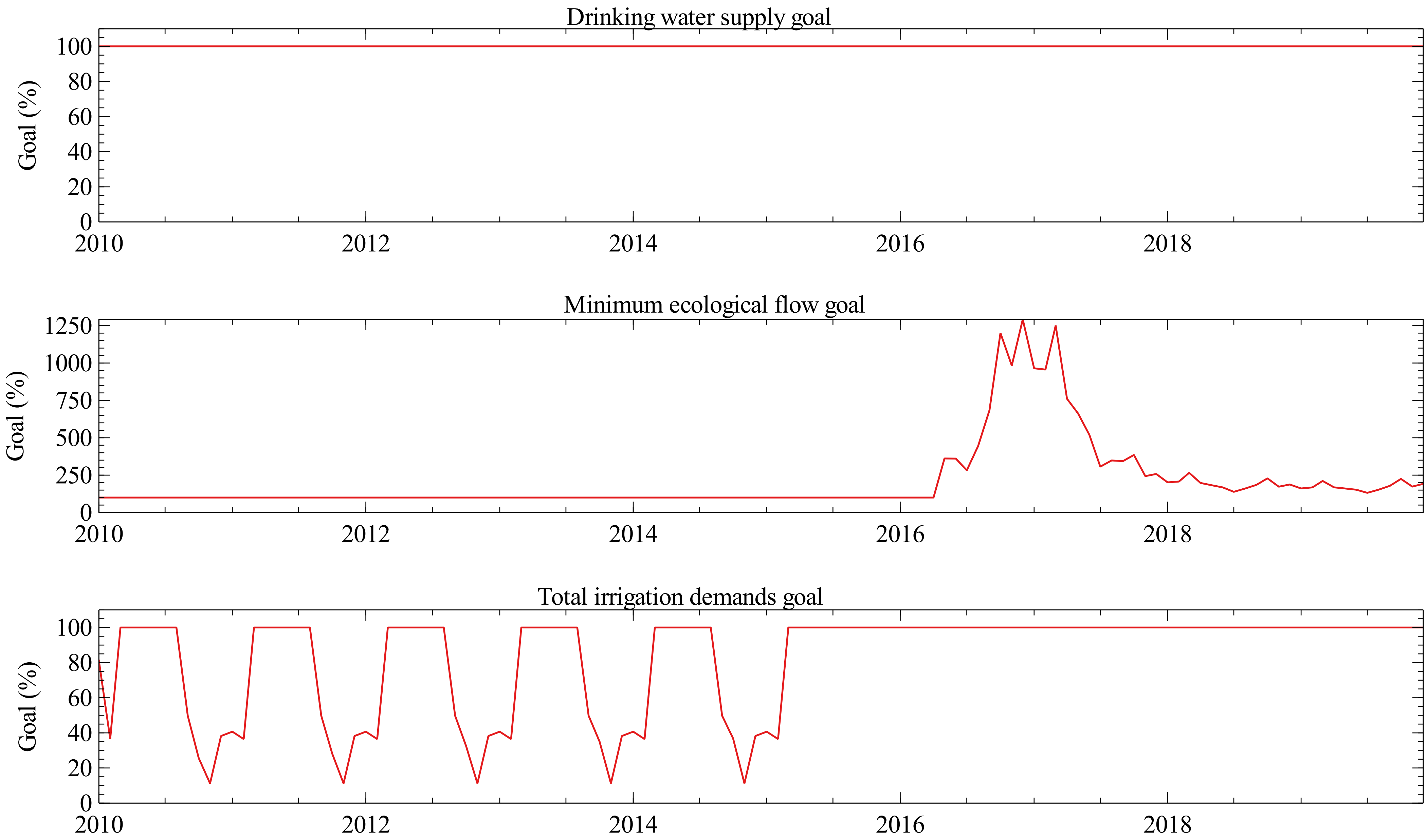


Drinking water supply



Irrigation demands analysis

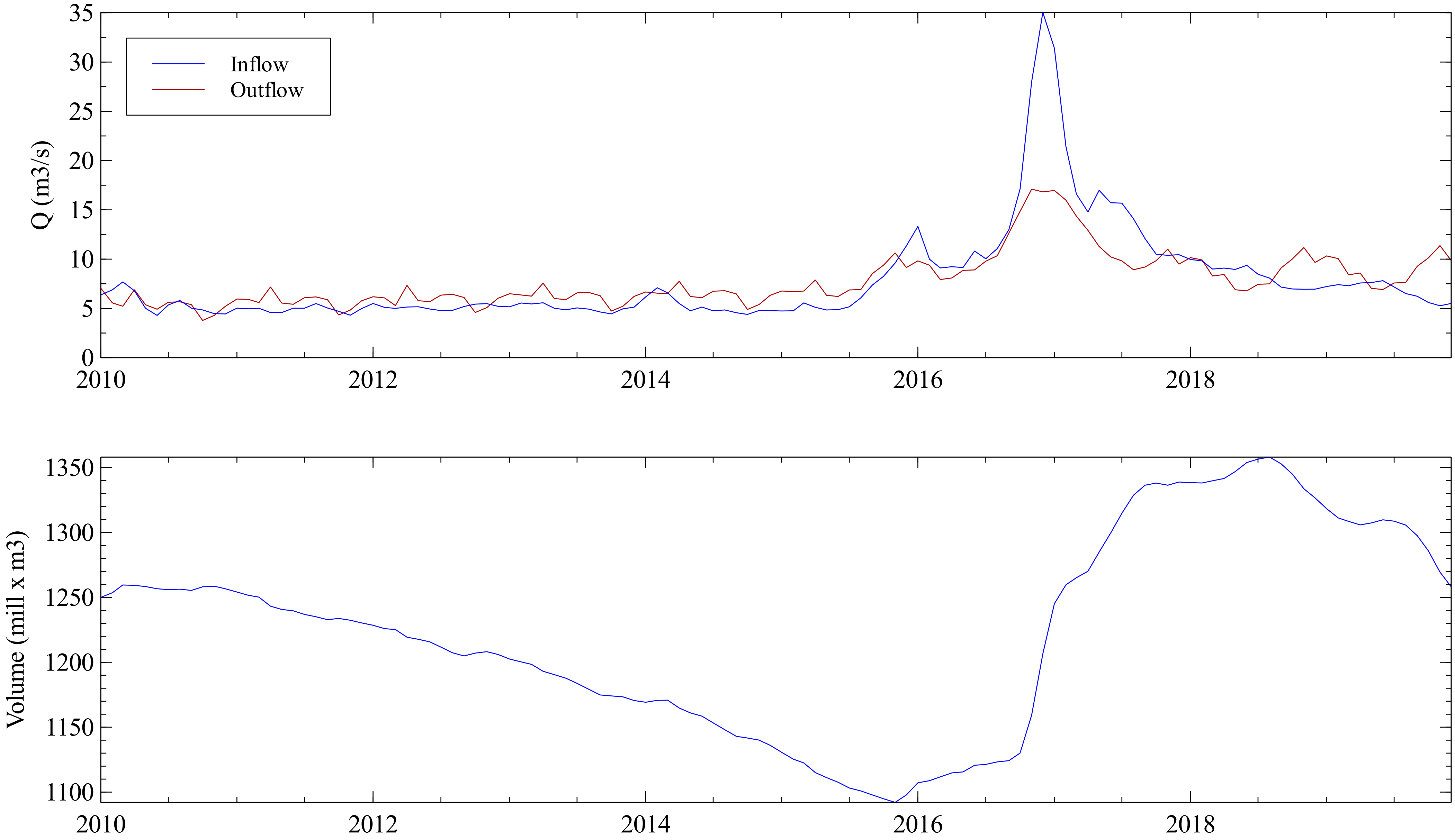
Goals analysis



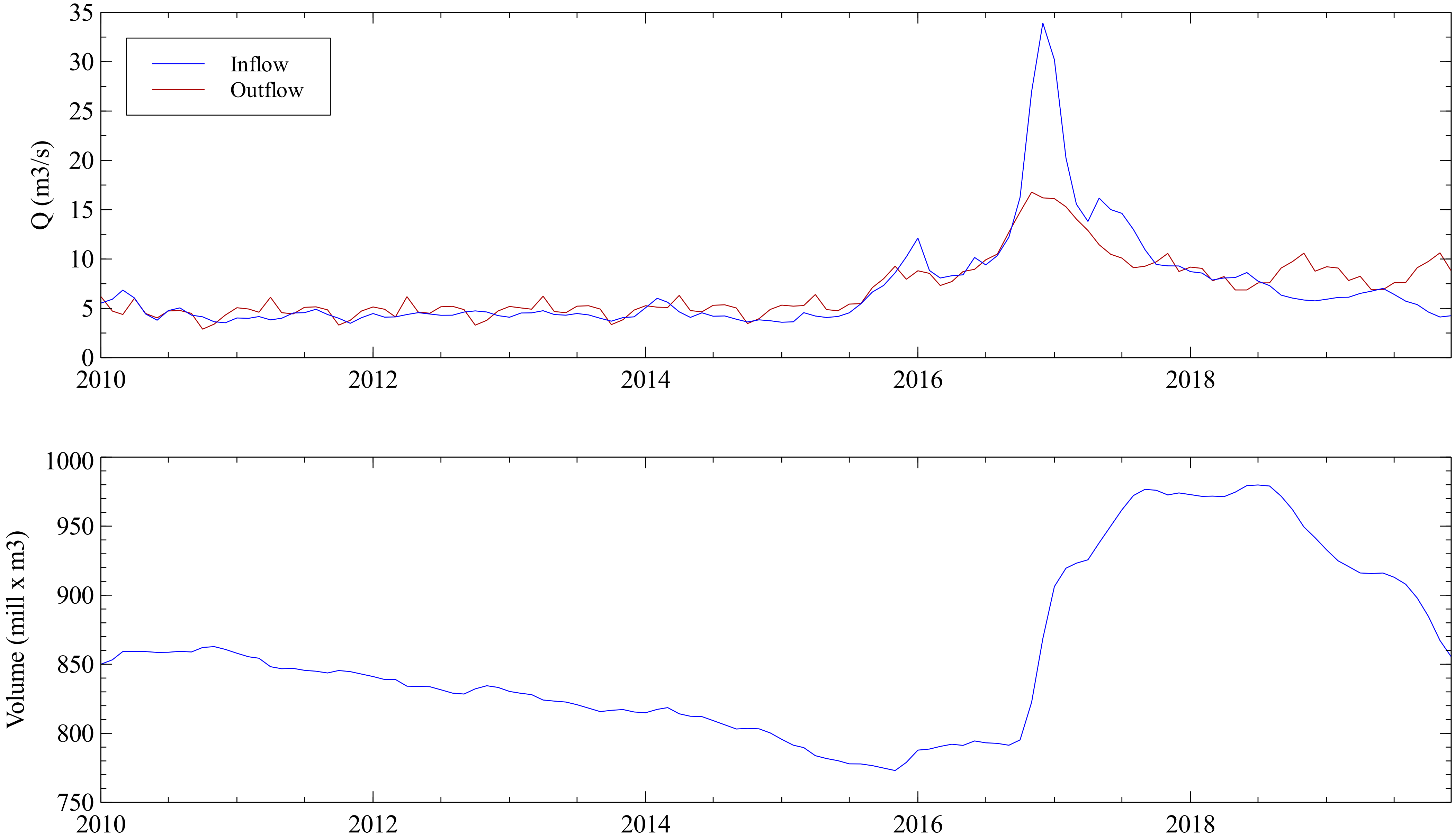
Appendix J

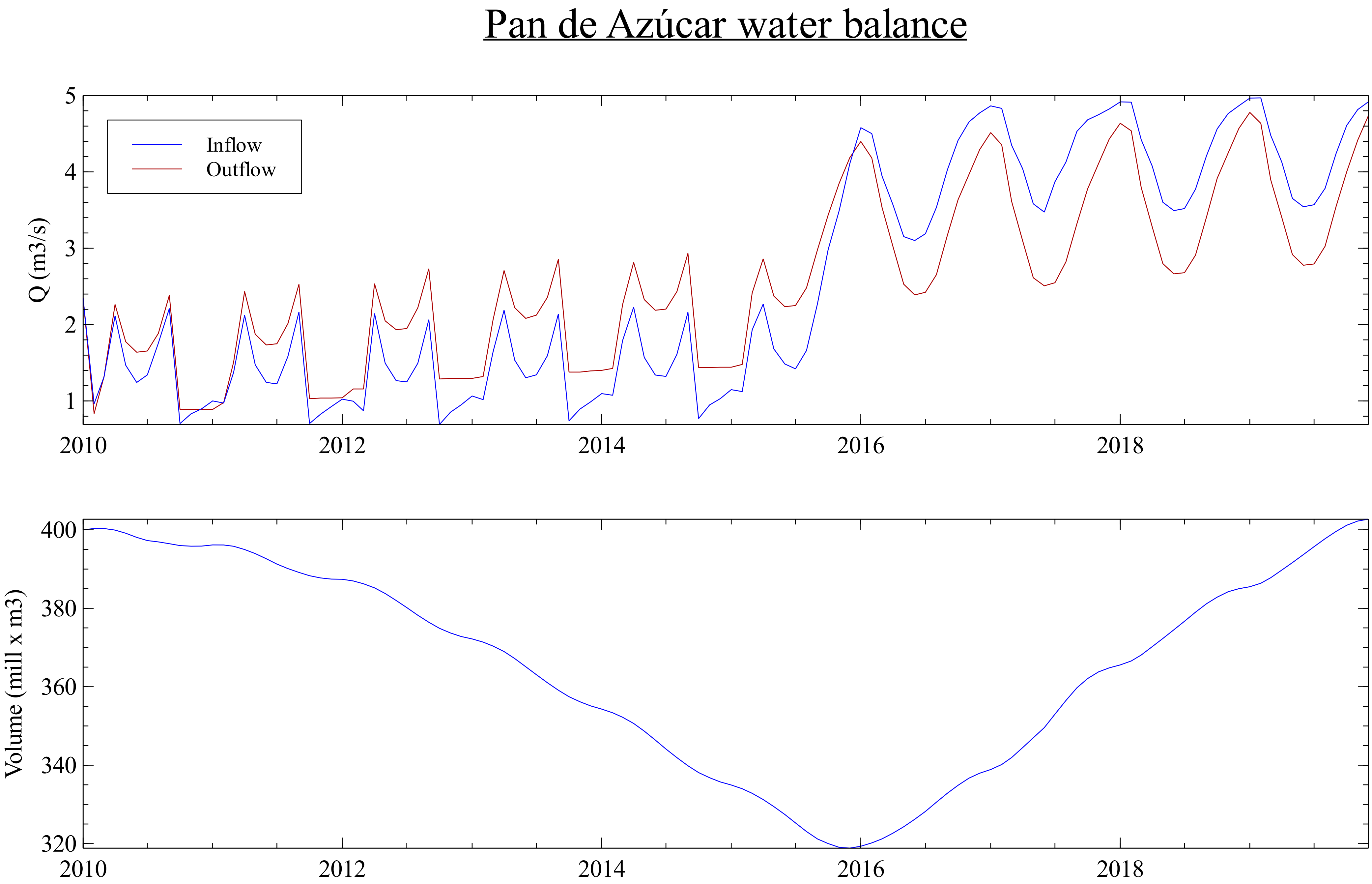
Scenario A

Total water balance

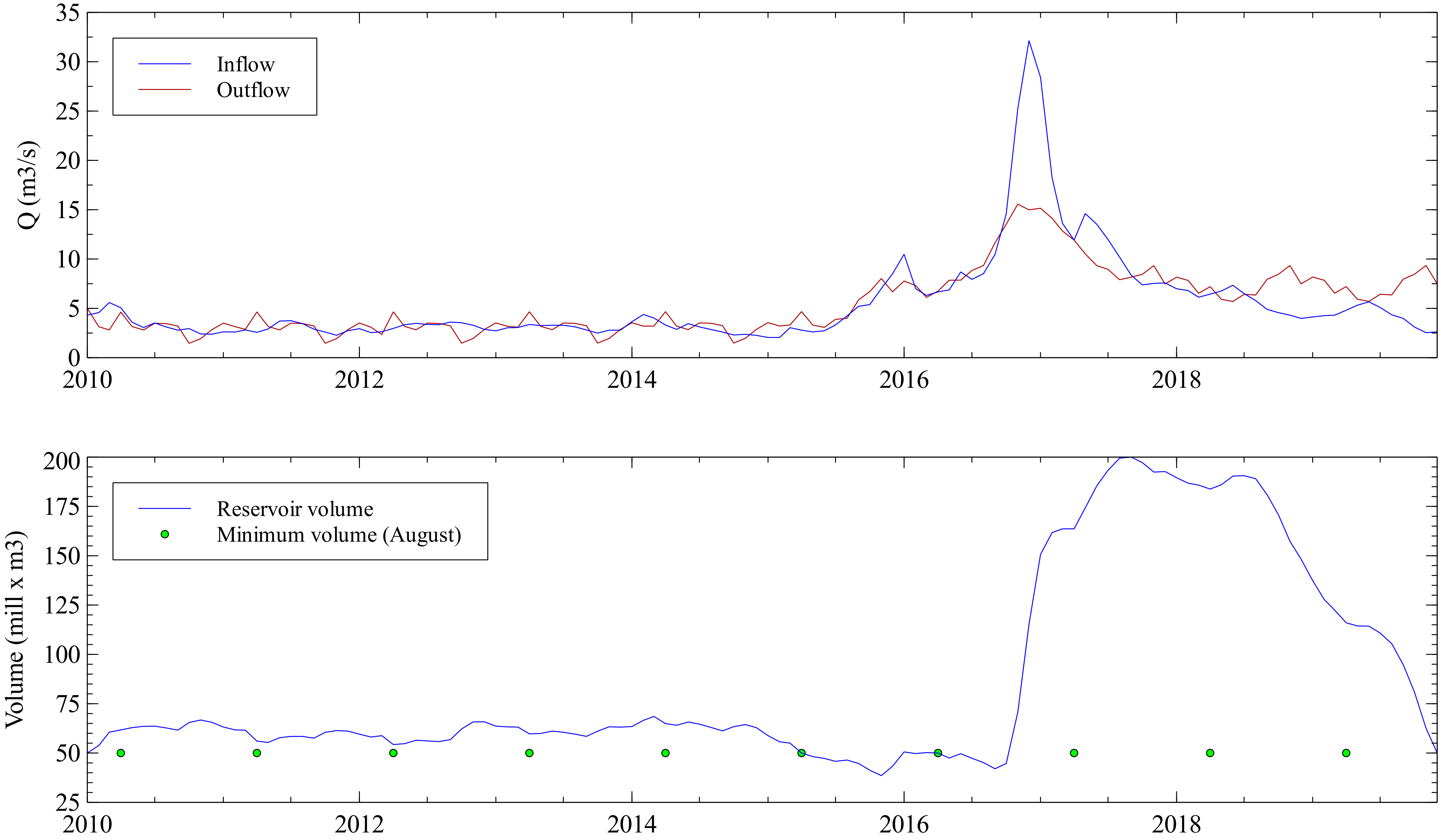


Elqui water balance

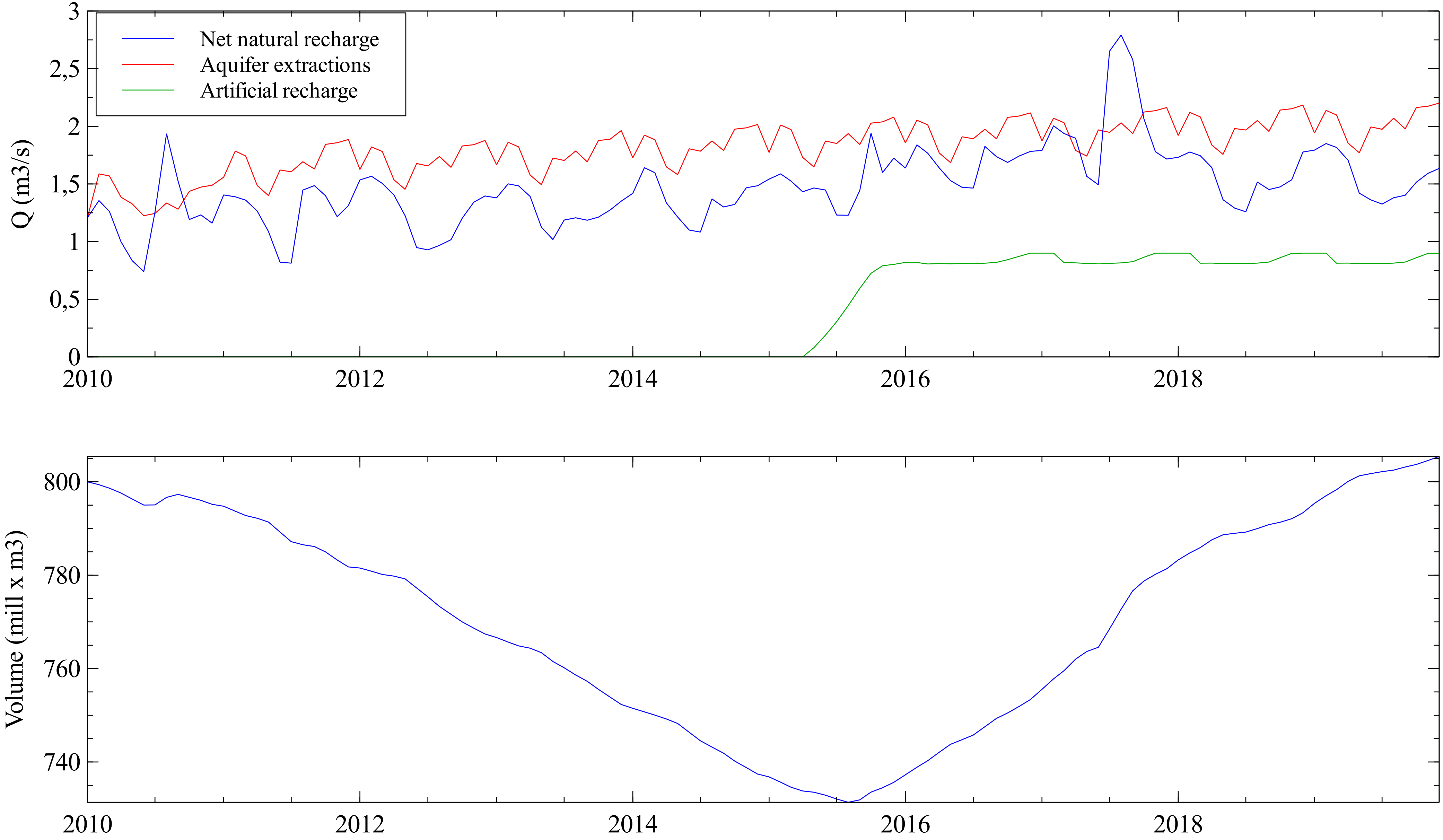



Pan de Azúcar water balance
Inflow
Outflow
Q (m3/s)
5
4
3
2
1
2010
2012
2014
2016
2018
Volume (mill x m3)
400
380
360
340
320
2010
2012
2014
2016
2018

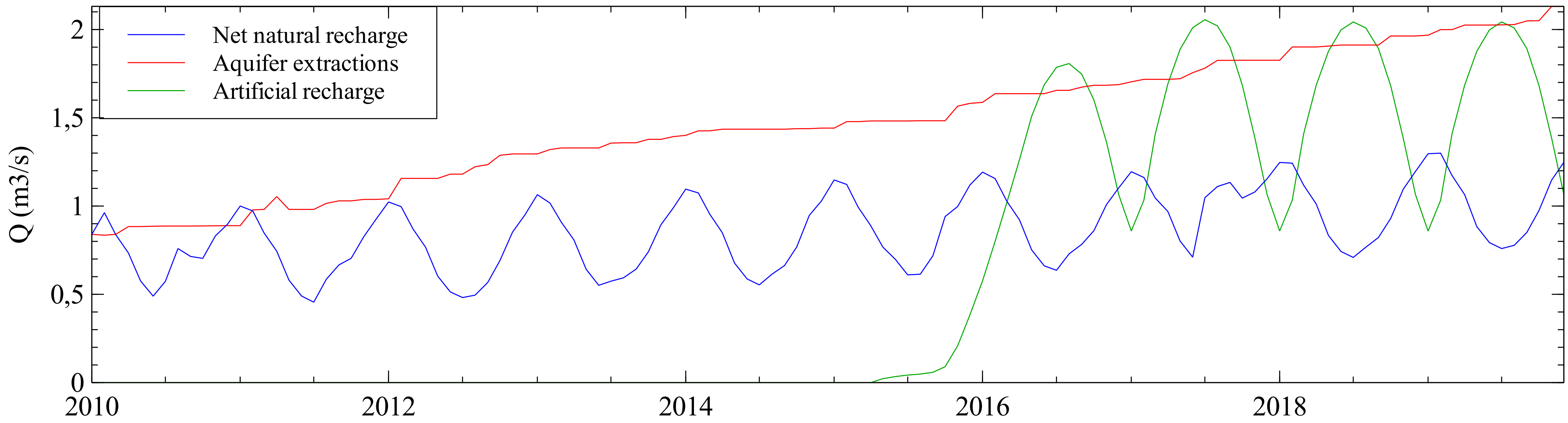
Puclaro reservoir

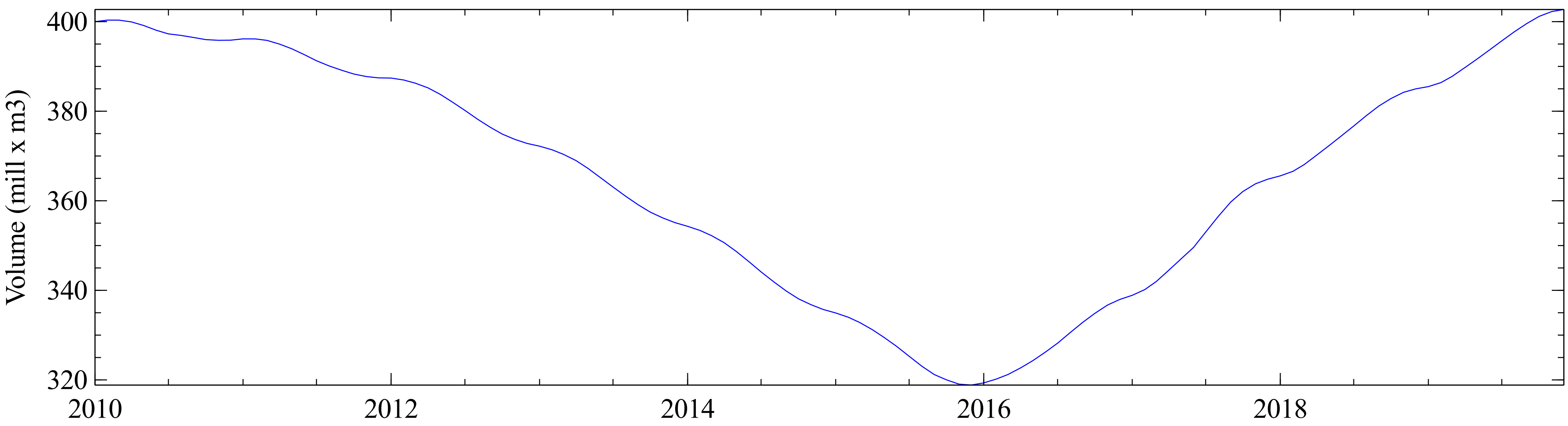


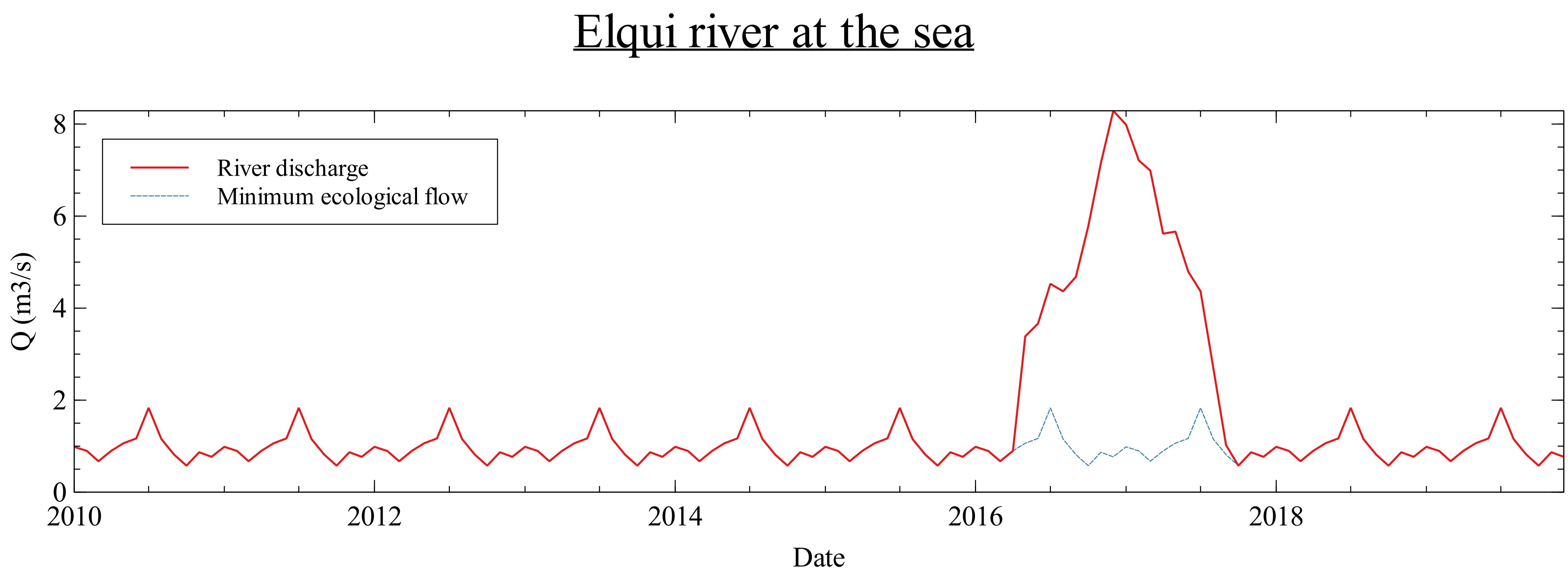
Elqui aquifer



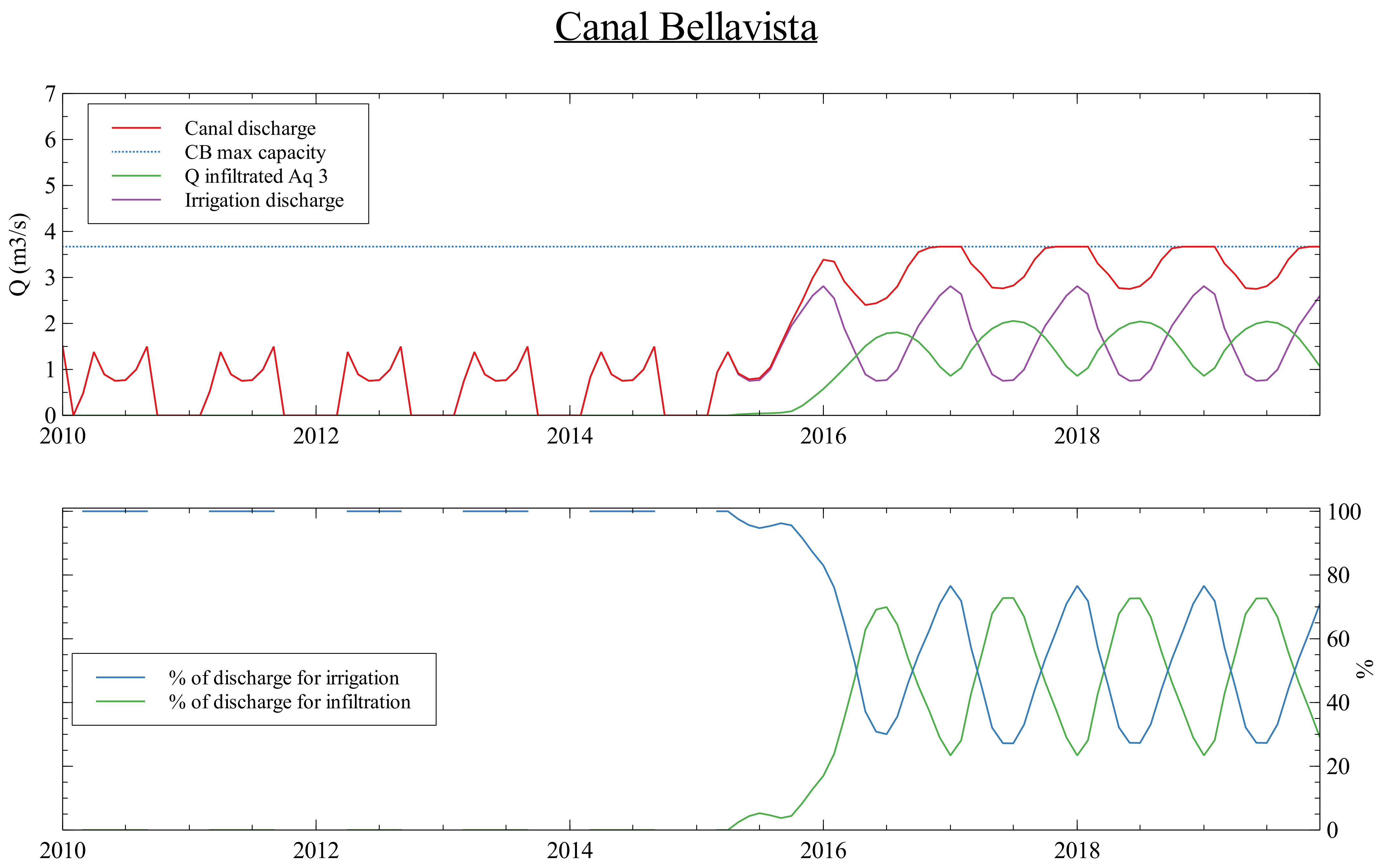
Pan de Azúcar aquifer



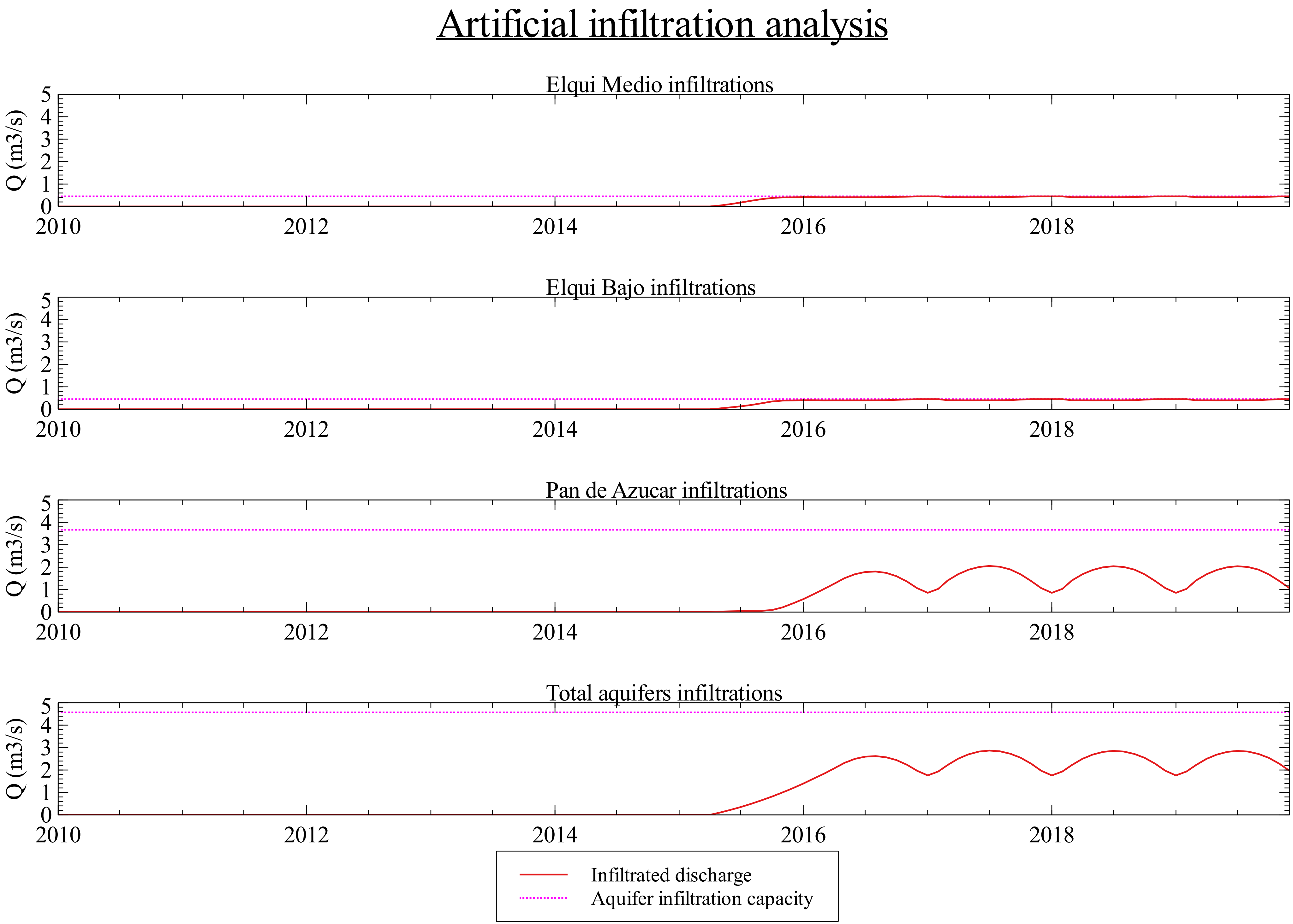




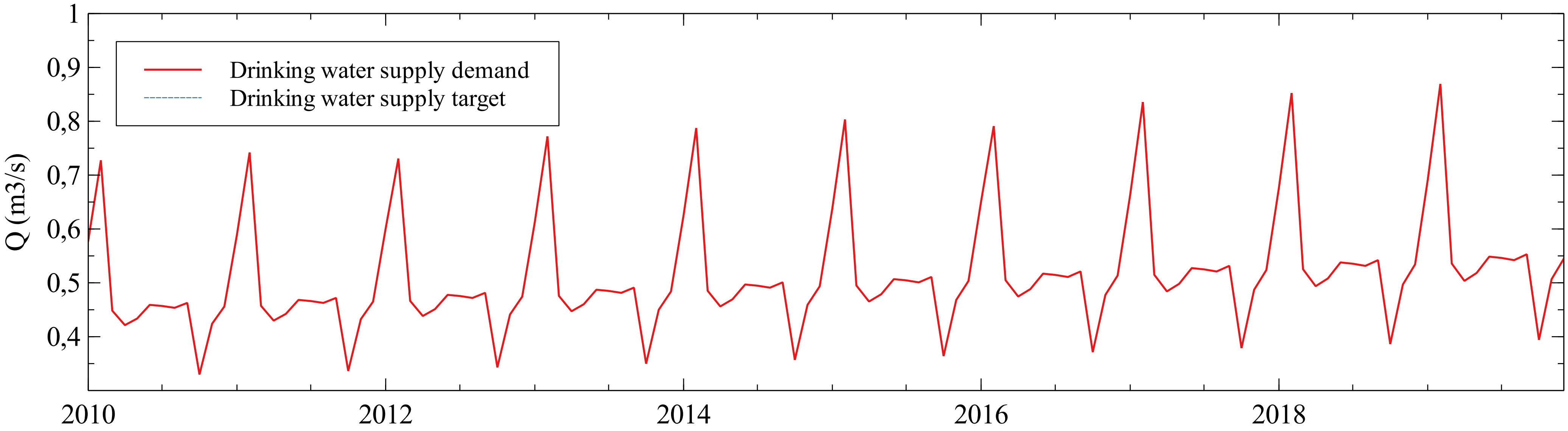
Elqui river at the sea
River discharge
Minimum ecological flow
Q (m3/s)
0
2
4
6
8
2010
2012
2014
2016
2018
Date



Canal Bellavista
Canal discharge
CB max capacity
Q infiltrated Aq 3
Irrigation discharge
Q (m3/s)
0
1
2
3
4
5
6
7
2010
2012
2014
2016
2018
% of discharge for irrigation
% of discharge for infiltration
%
0
20
40
60
80
100
2010
2012
2014
2016
2018

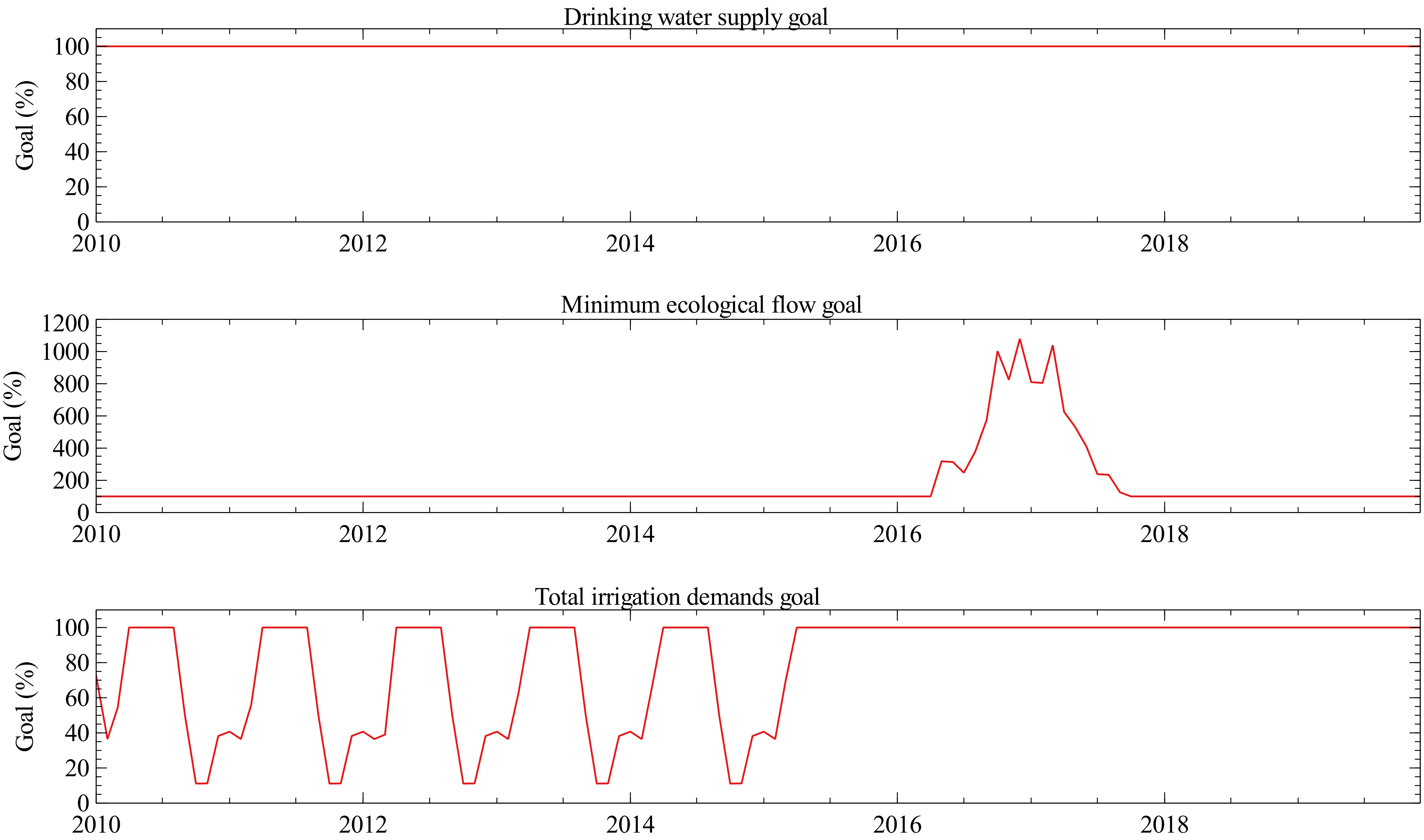

Artificial infiltration analysis
Elqui Medio infiltrations
Elqui Bajo infiltrations
Pan de Azucar infiltrations
Total aquifers infiltrations
Q (m3/s)
0
1
2
3
4
5
2010
2012
2014
2016
2018
Infiltrated discharge
Aquifer infiltration capacity

Drinking water supply



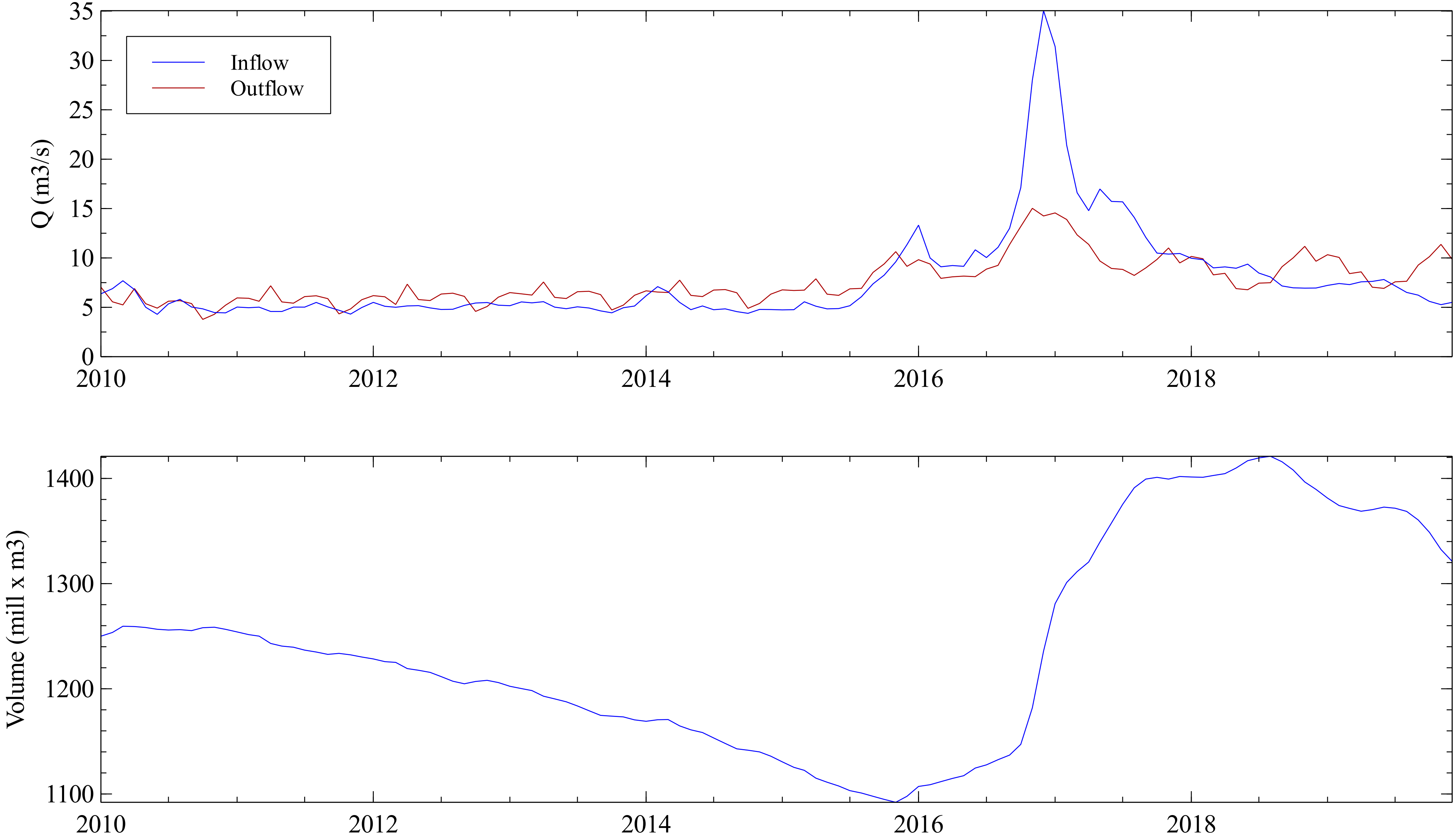
Irrigation demands analysis

Goals analysis

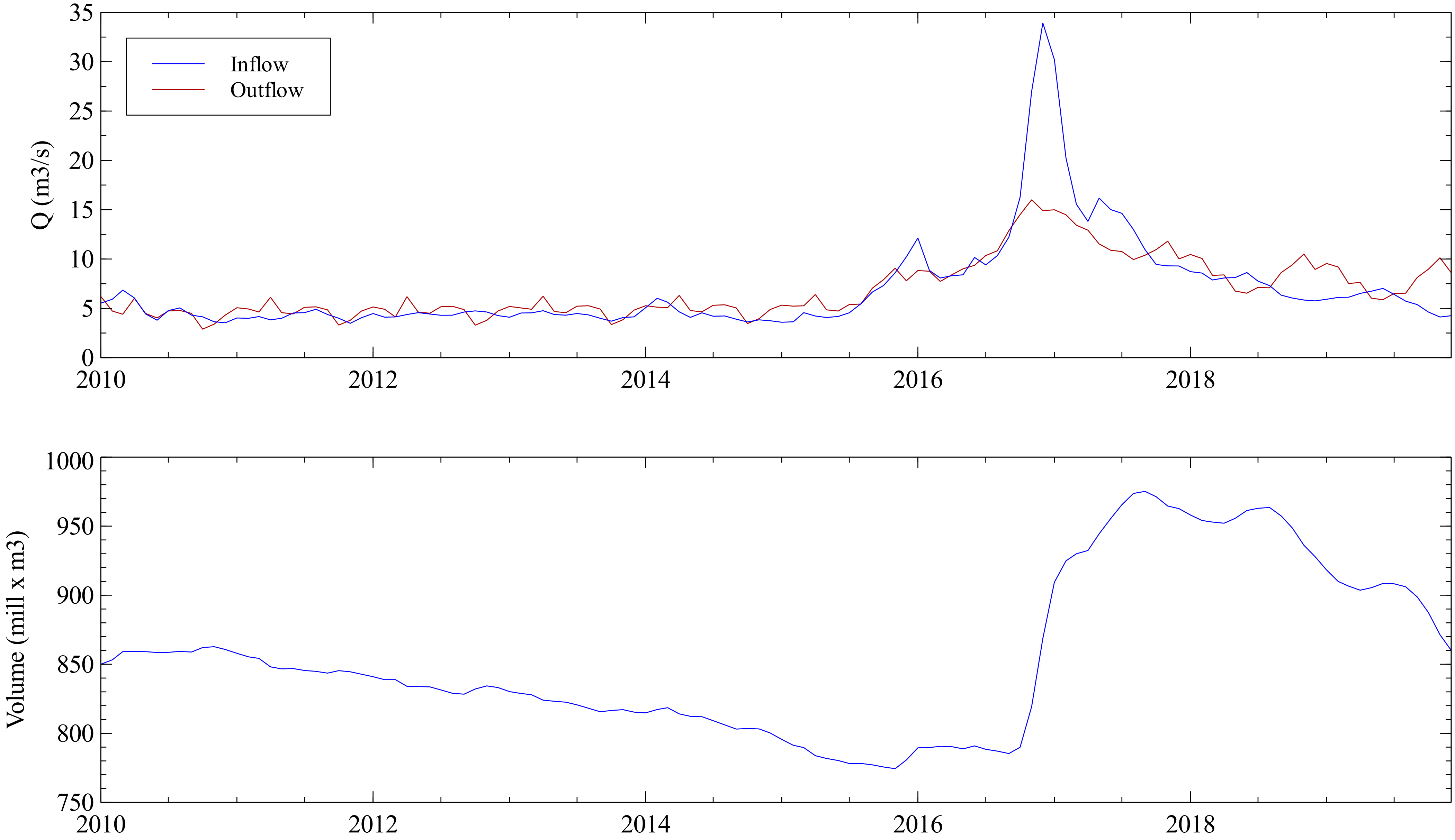


Appendix K
Scenario B

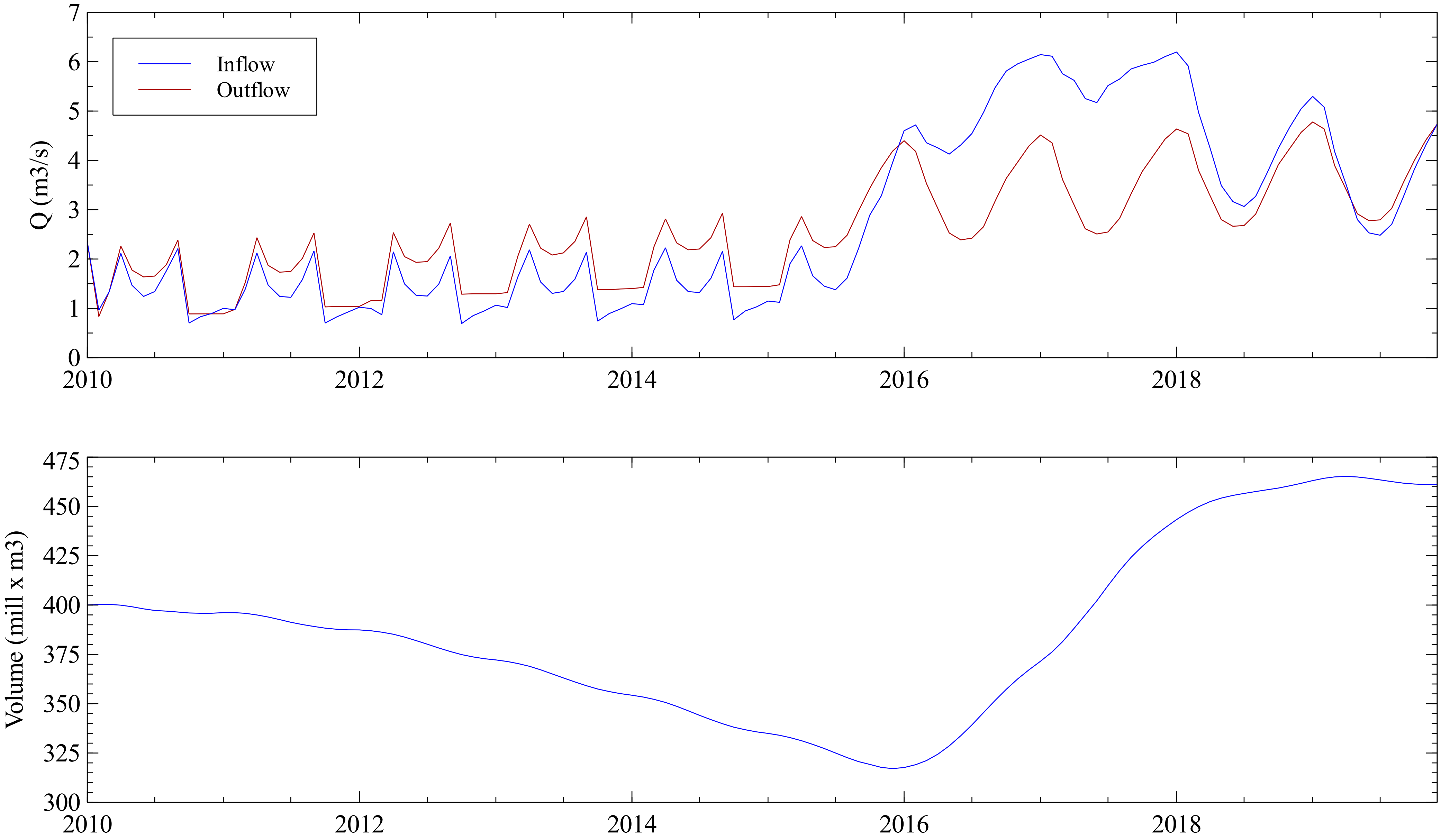
Total water balance



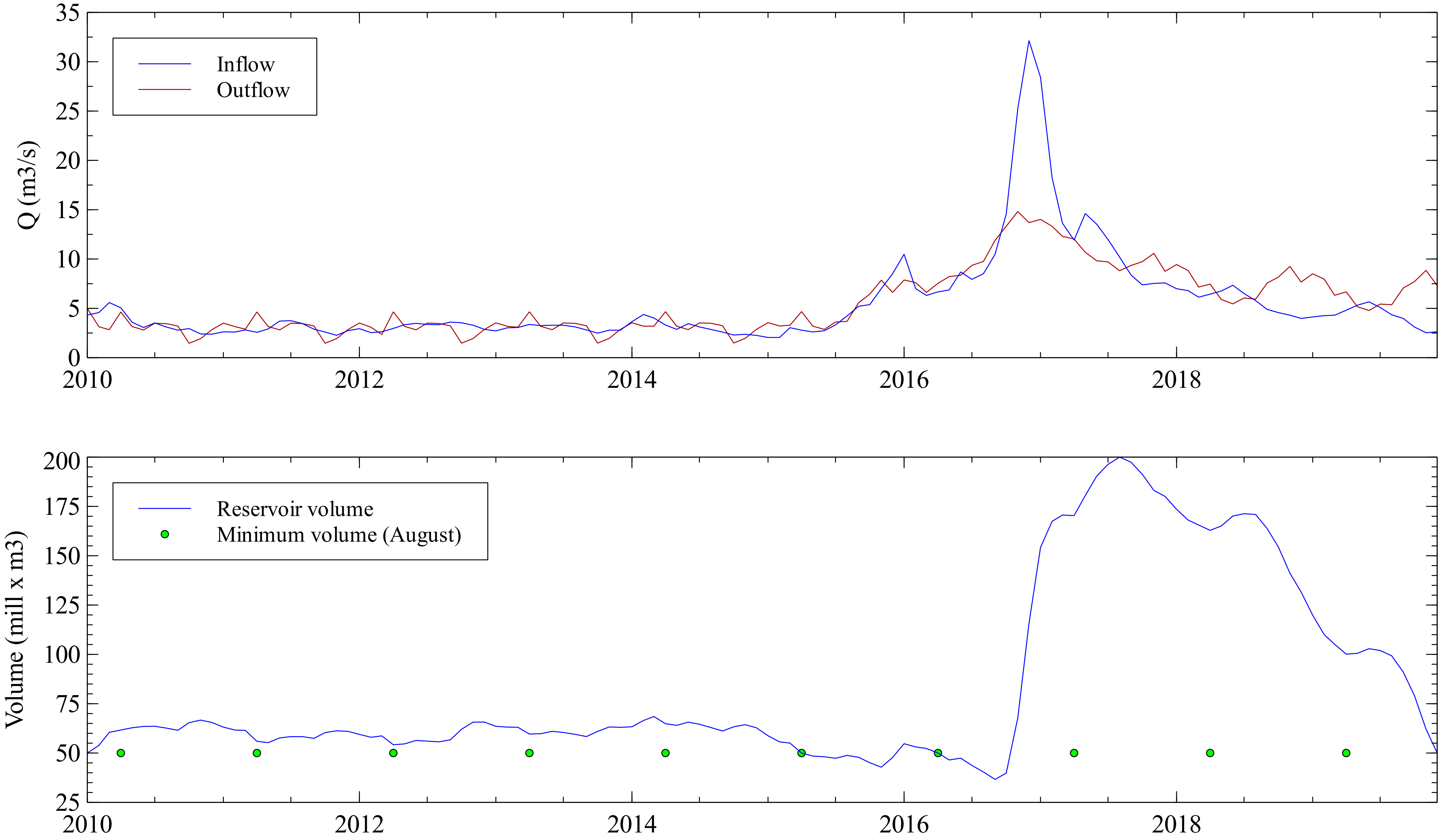
Elqui water balance



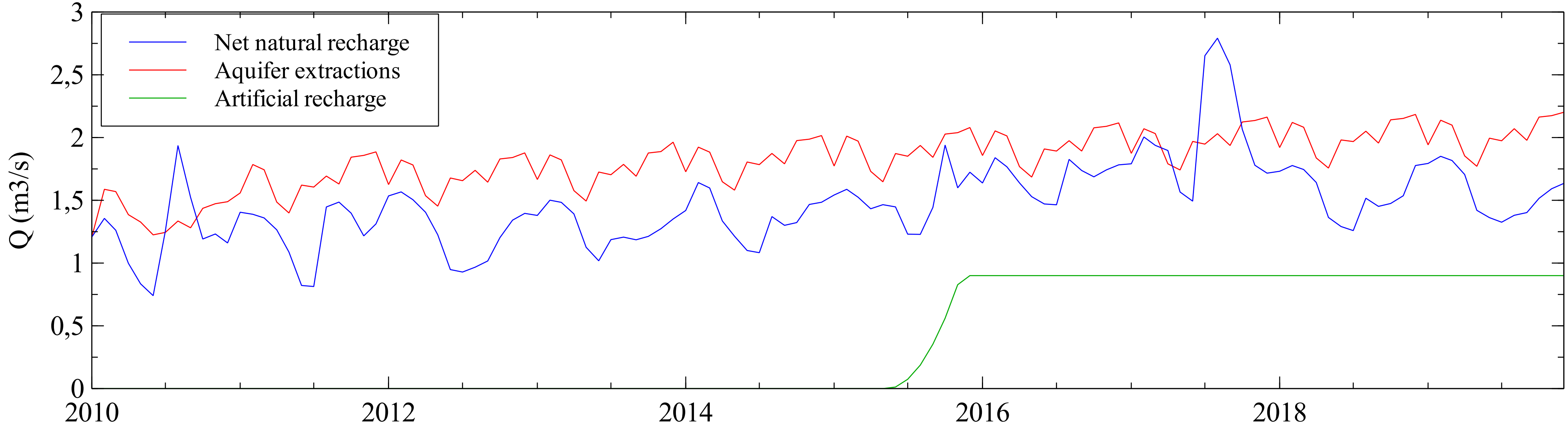
Pan de Azúcar water balance

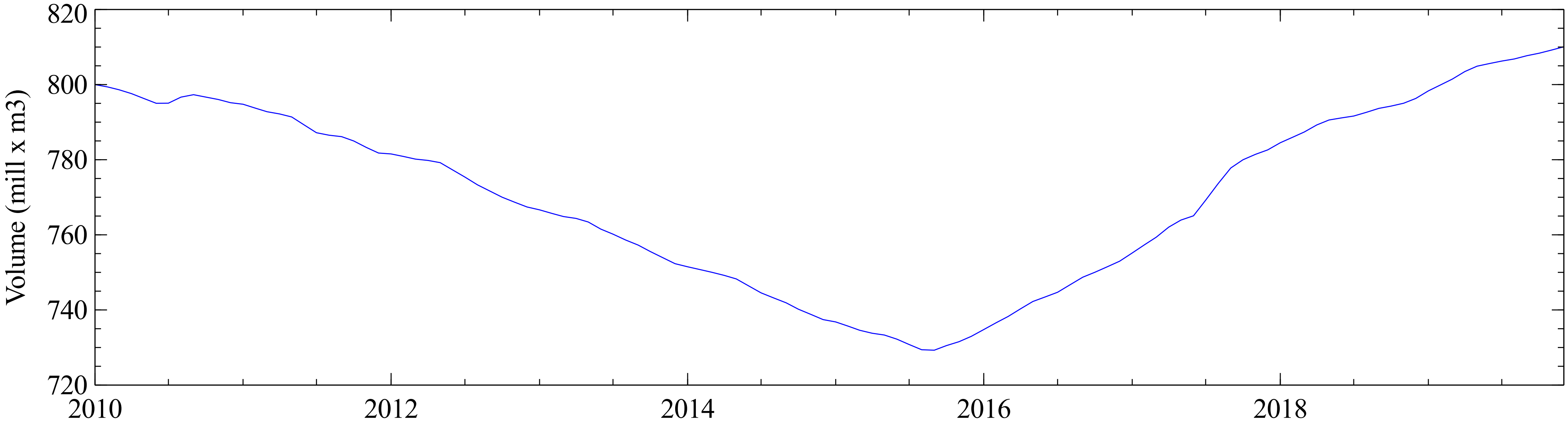


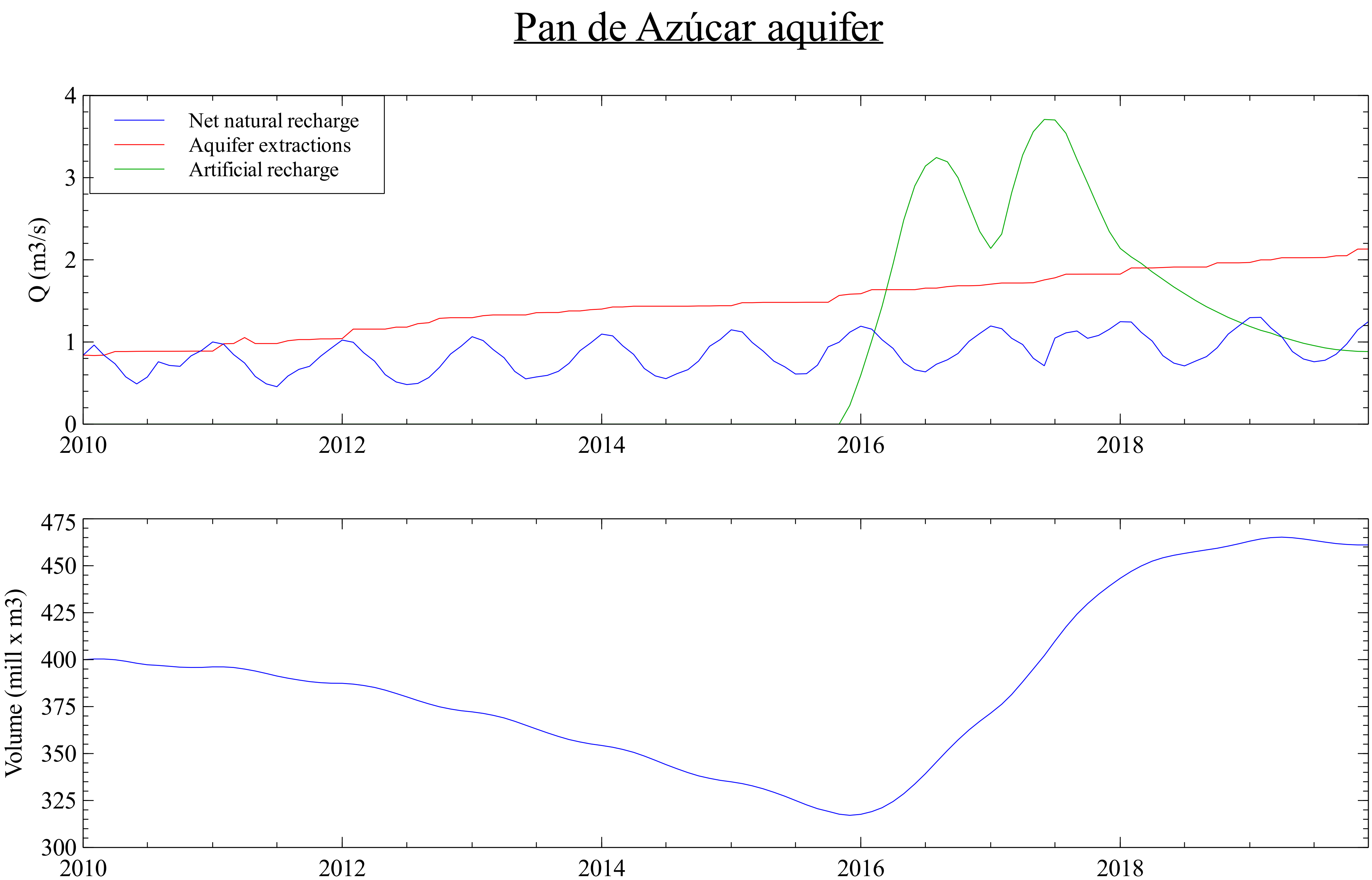
Puclaro reservoir



Elqui aquifer

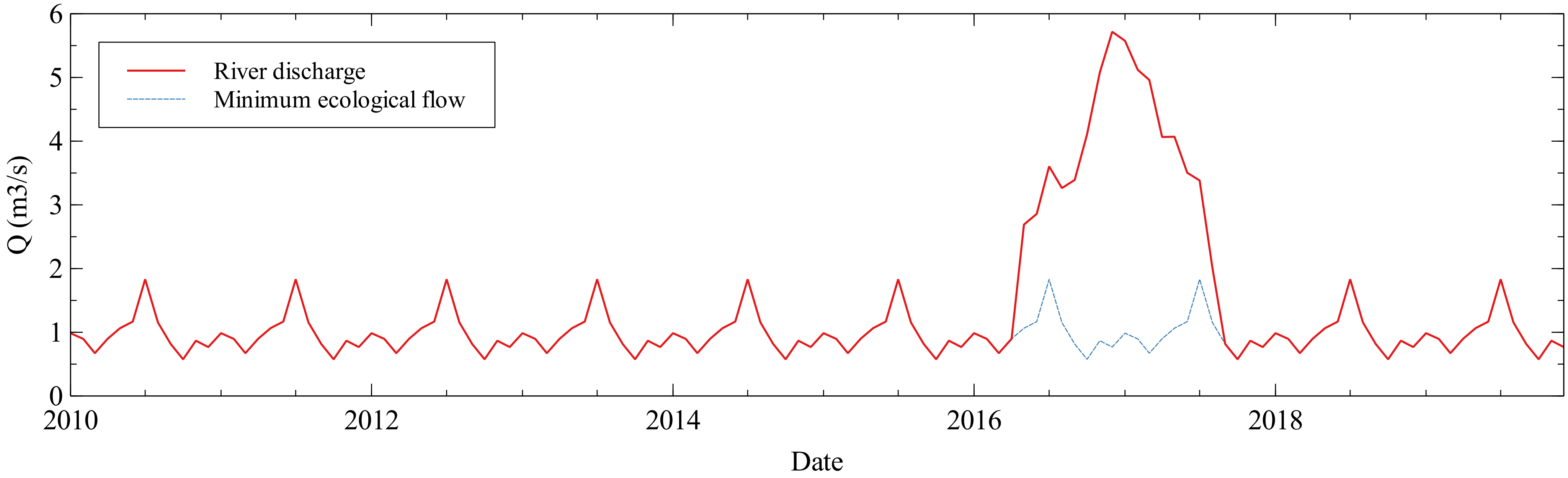




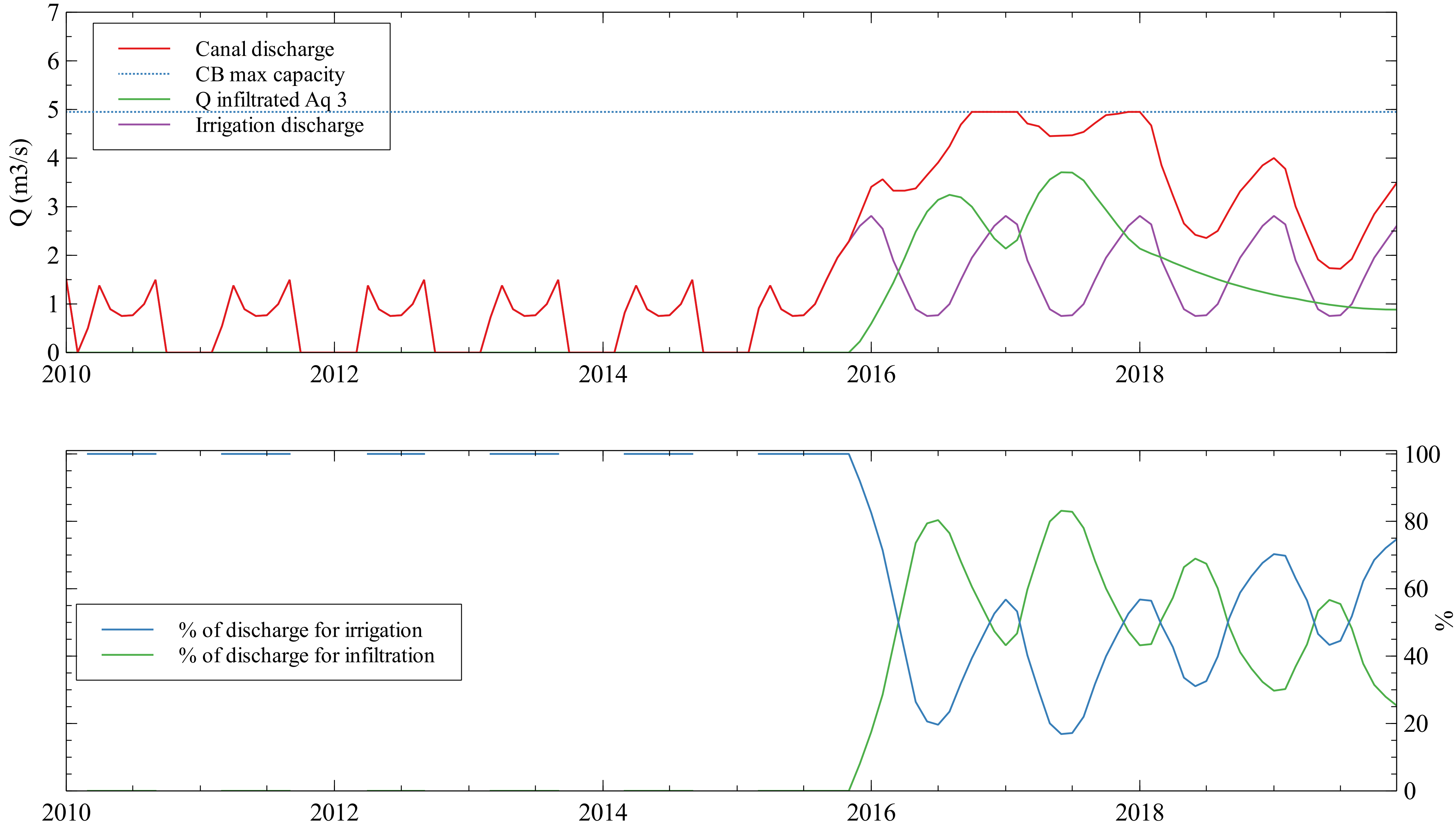


Pan de Azúcar aquifer
Net natural recharge
Aquifer extractions
Artificial recharge
Q (m3/s)
0
1
2
3
4
2010
2012
2014
2016
2018
Volume (mill x m3)
300
325
350
375
400
425
450
475
2010
2012
2014
2016
2018

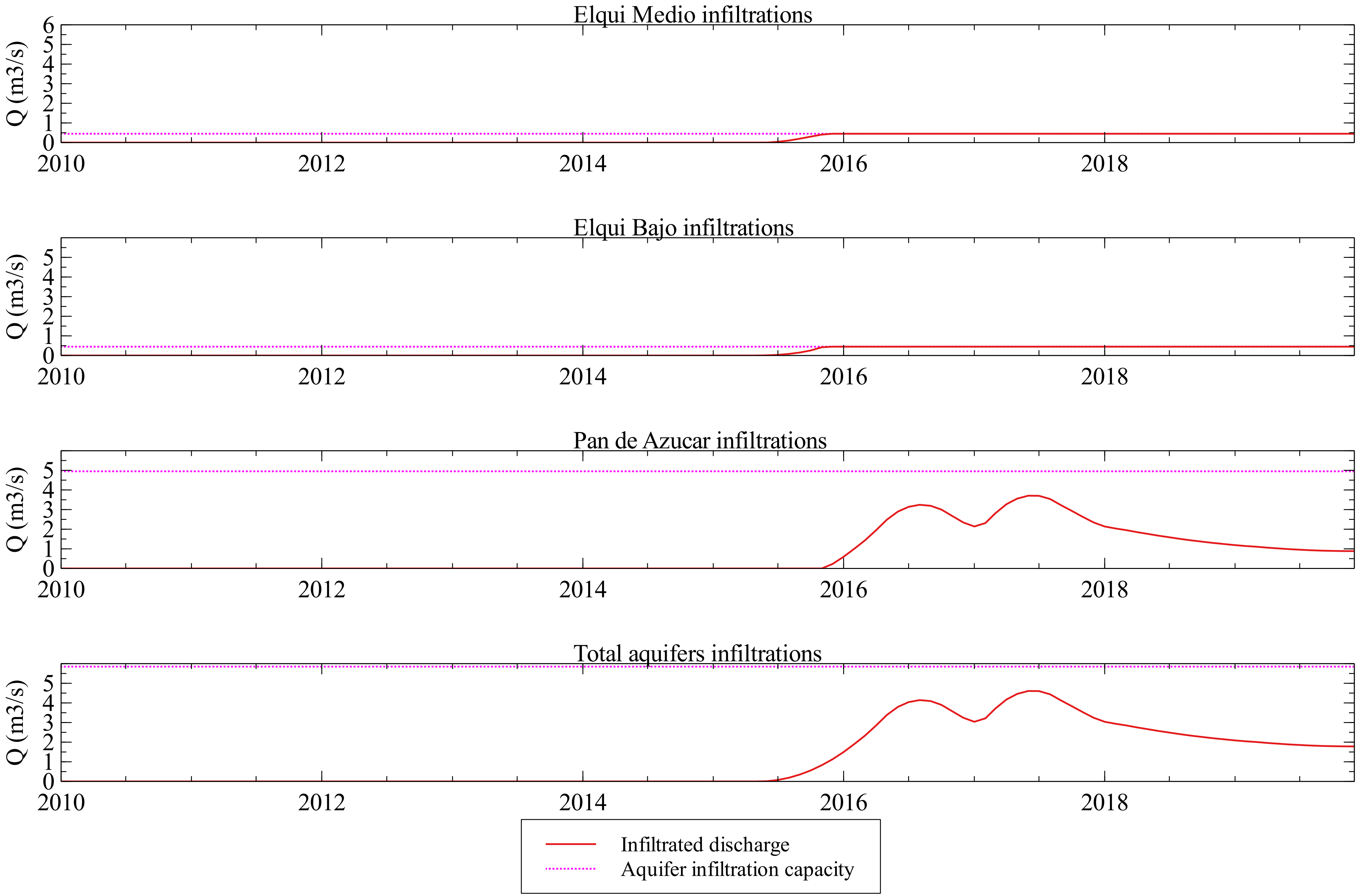
Elqui river at the sea



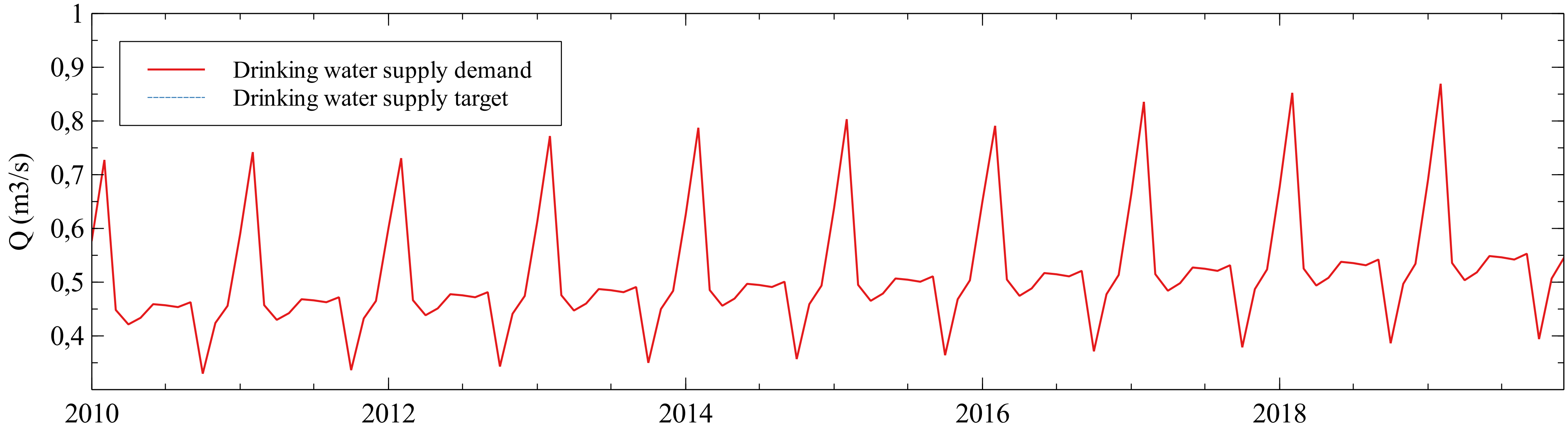
Canal Bellavista

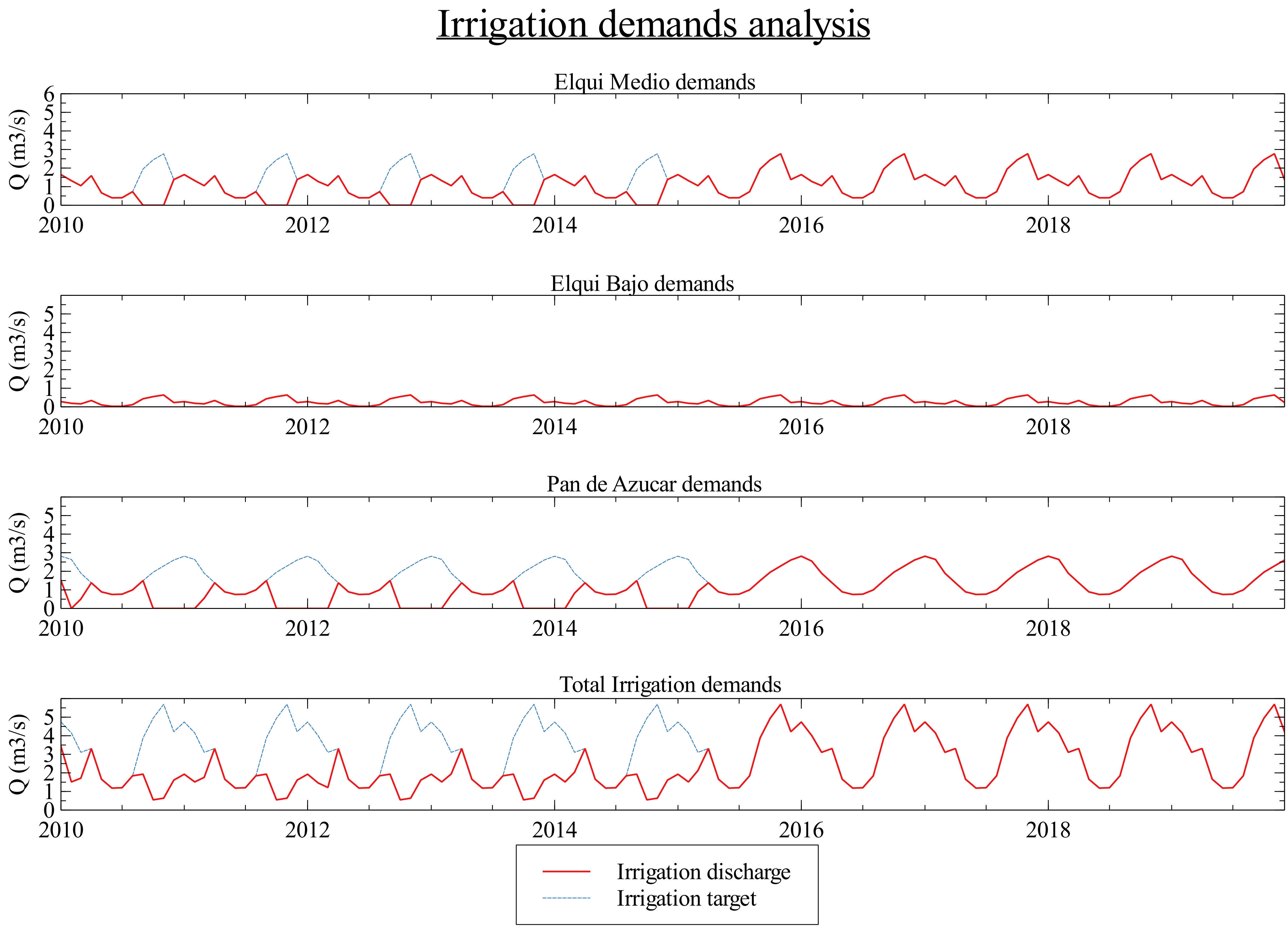


Artificial infiltration analysis



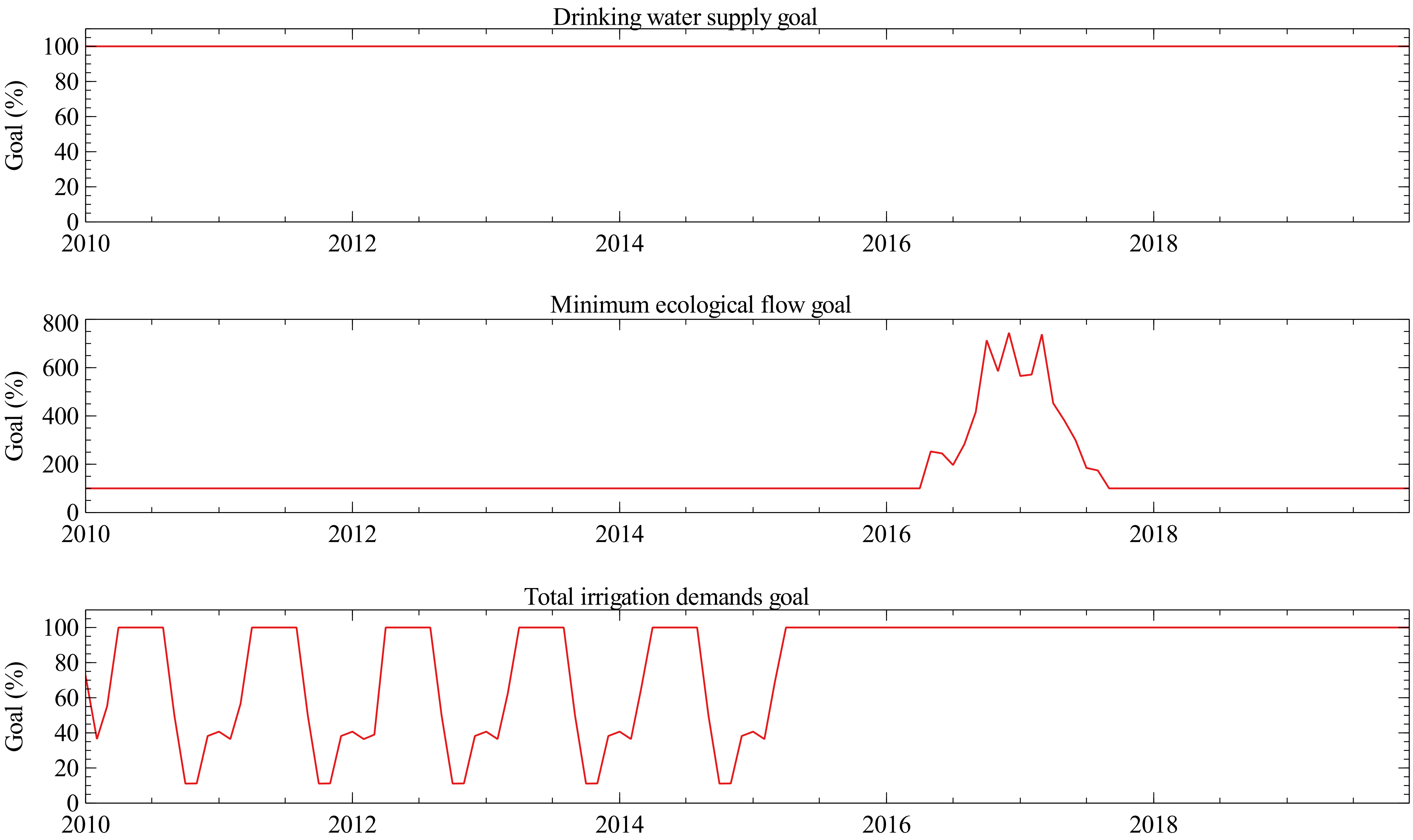
Drinking water supply





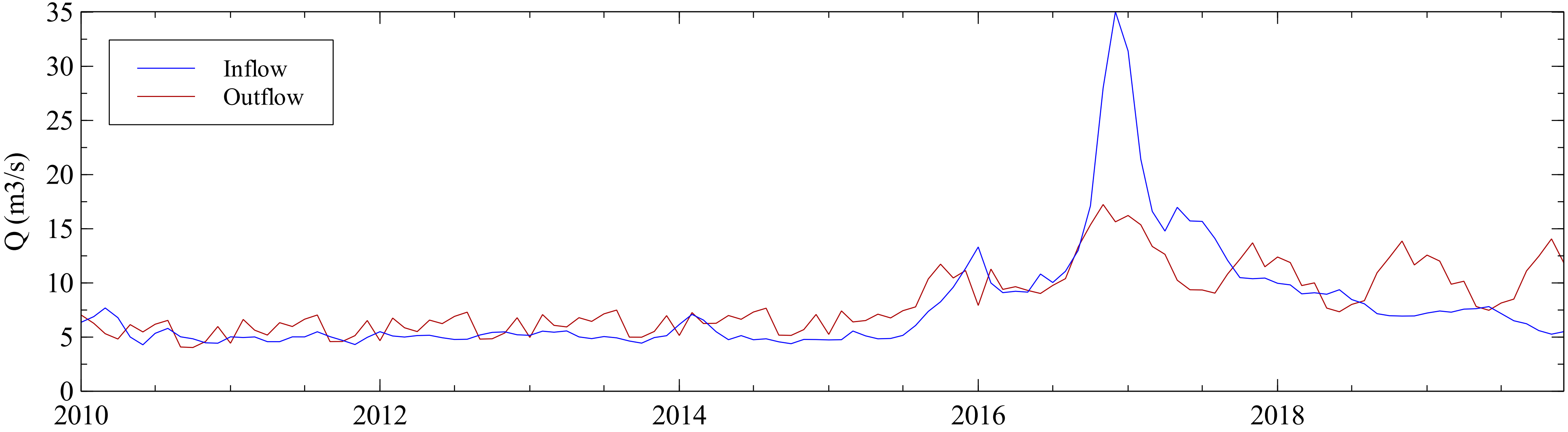
Irrigation demands analysis
Elqui Medio demands
Elqui Bajo demands
Pan de Azucar demands
Total Irrigation demands
Q (m3/s)
0
1
2
3
4
5
6
2010
2012
2014
2016
2018
Irrigation discharge
Irrigation target

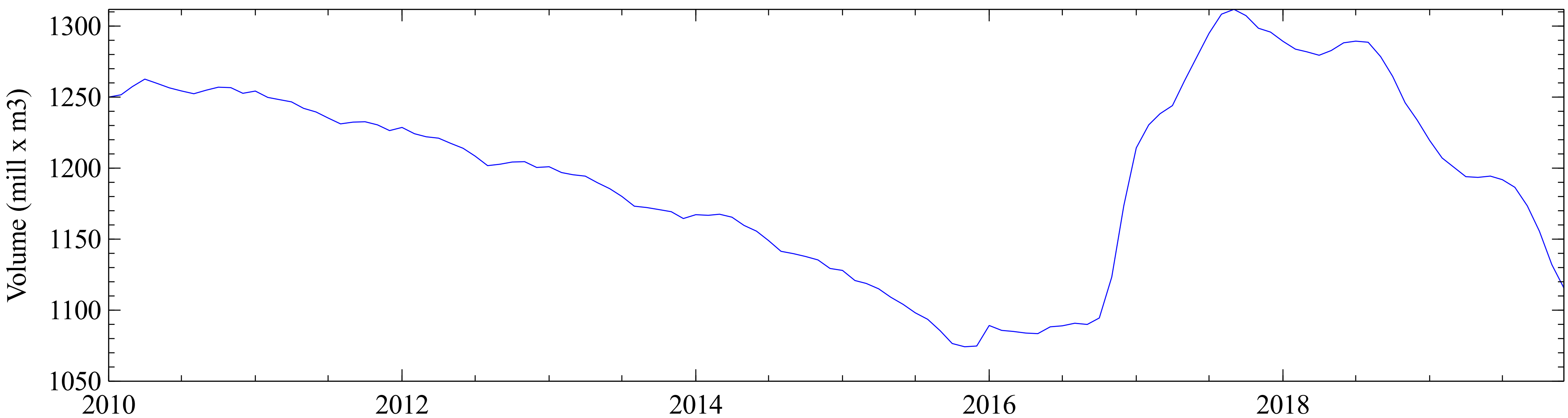
Goals analysis

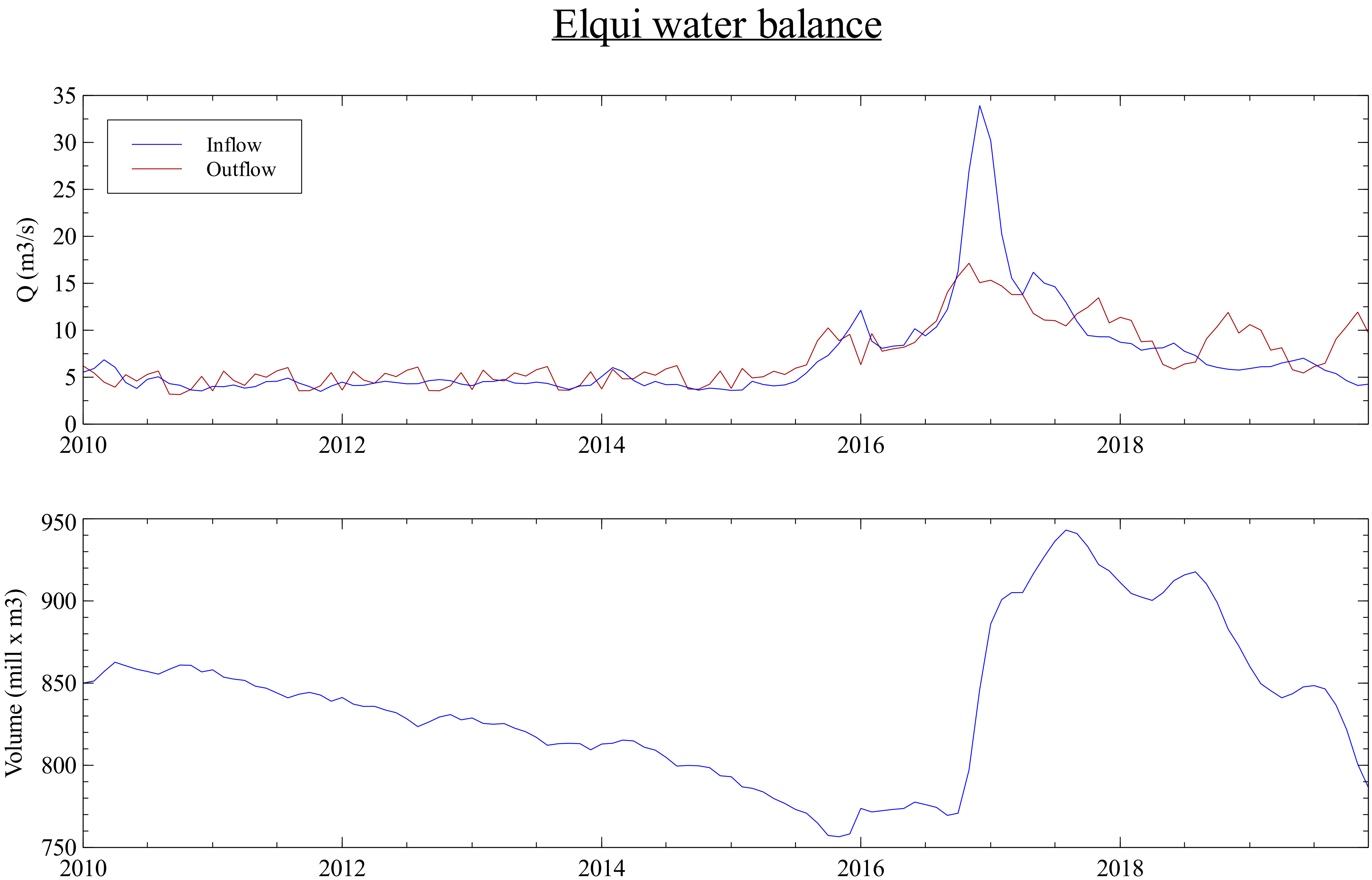


Appendix L
Scenario C

Total water balance

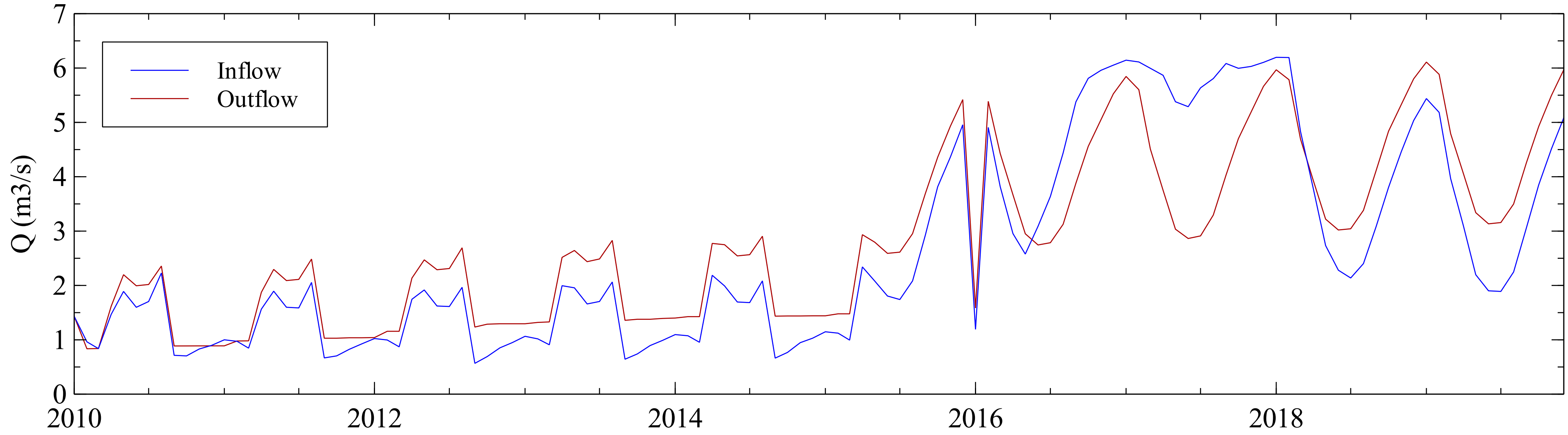


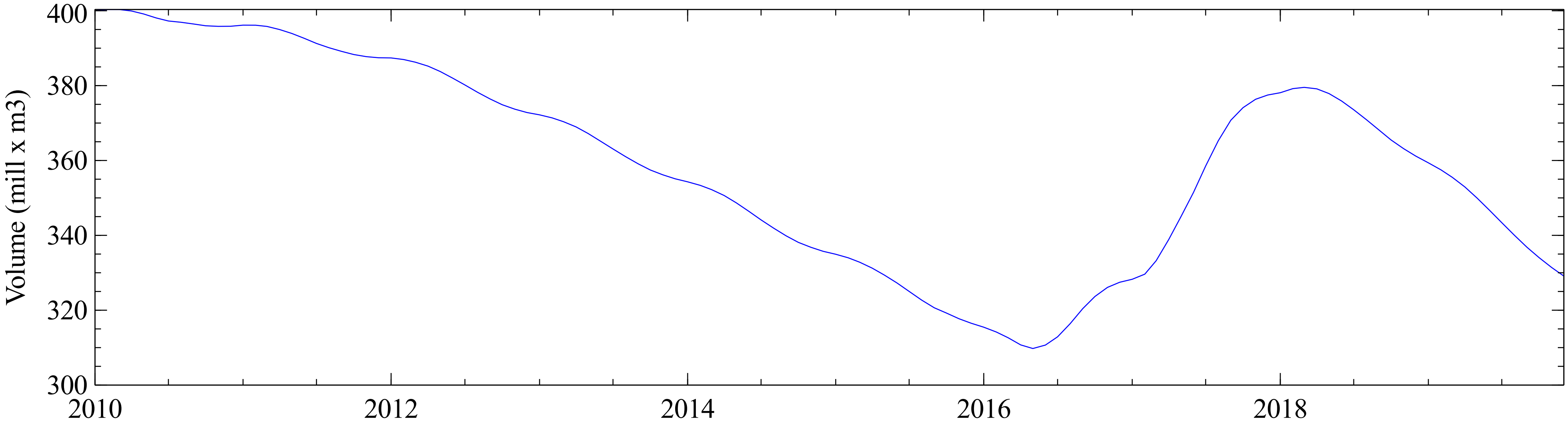




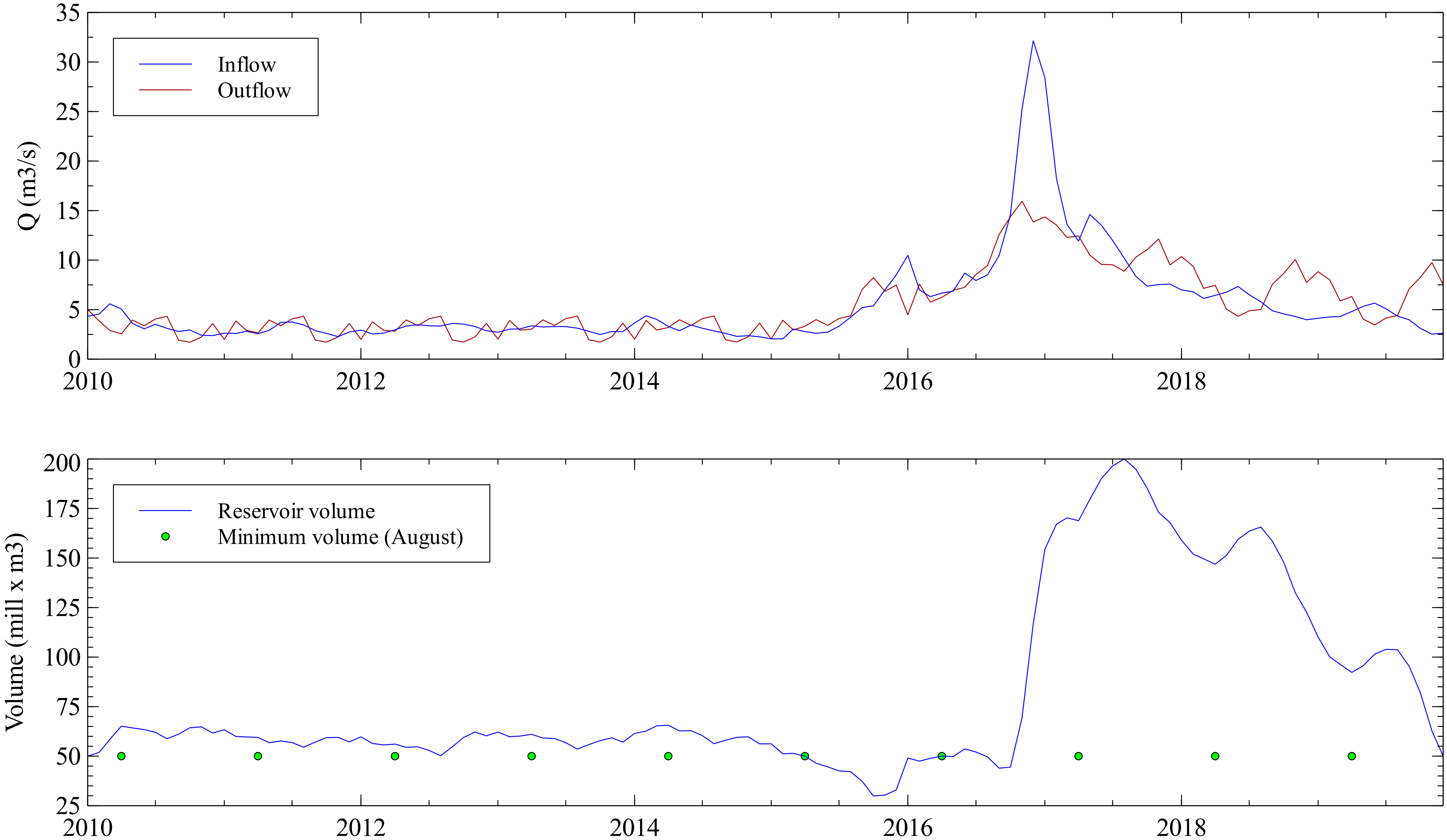
Elqui water balance
Inflow
Outflow
Q (m3/s)
35
30
25
20
15
10
5
0
2010
2012
2014
2016
2018
Volume (mill x m3)
950
900
850
800
750
2010
2012
2014
2016
2018

Pan de Azúcar water balance

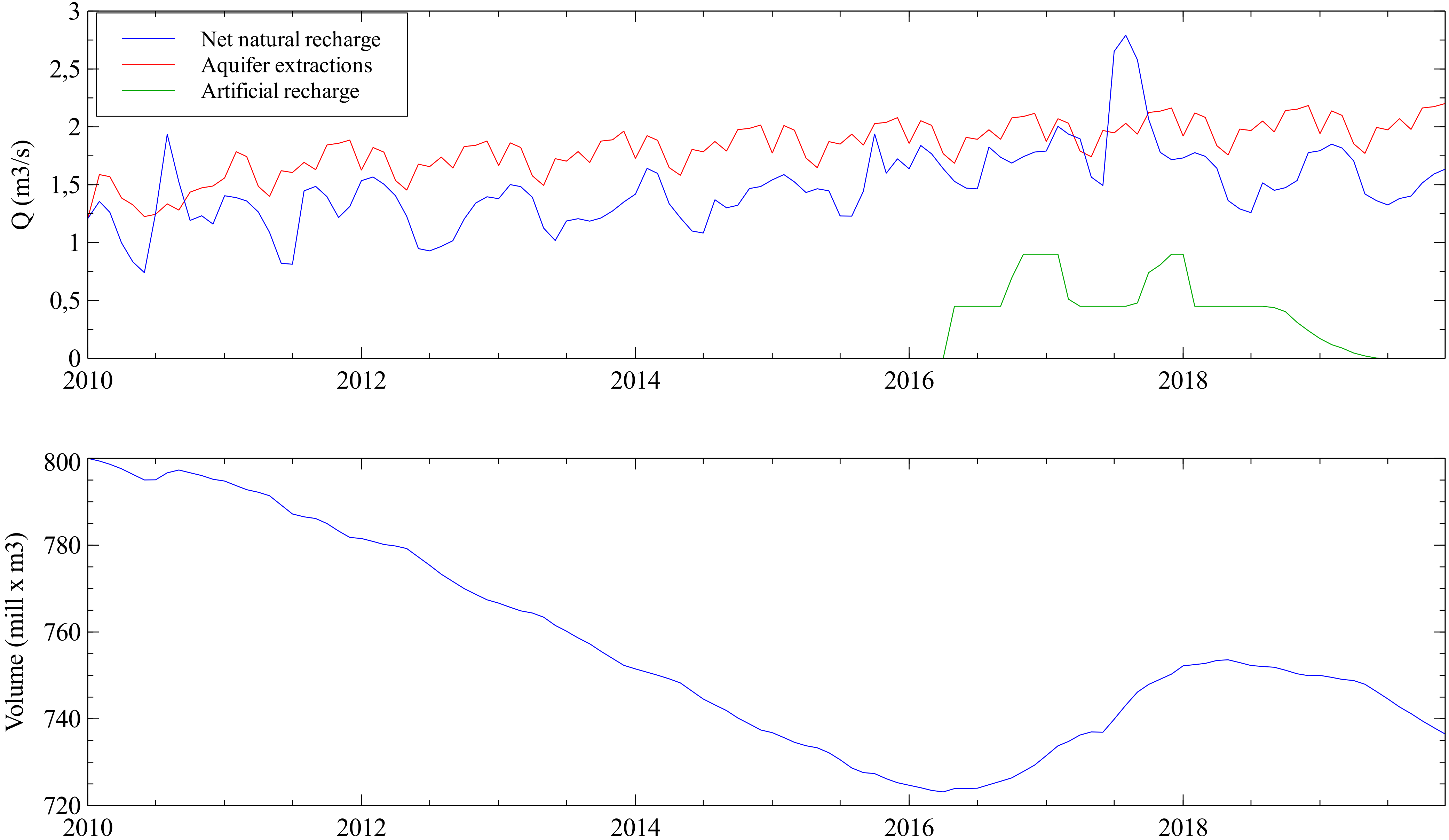




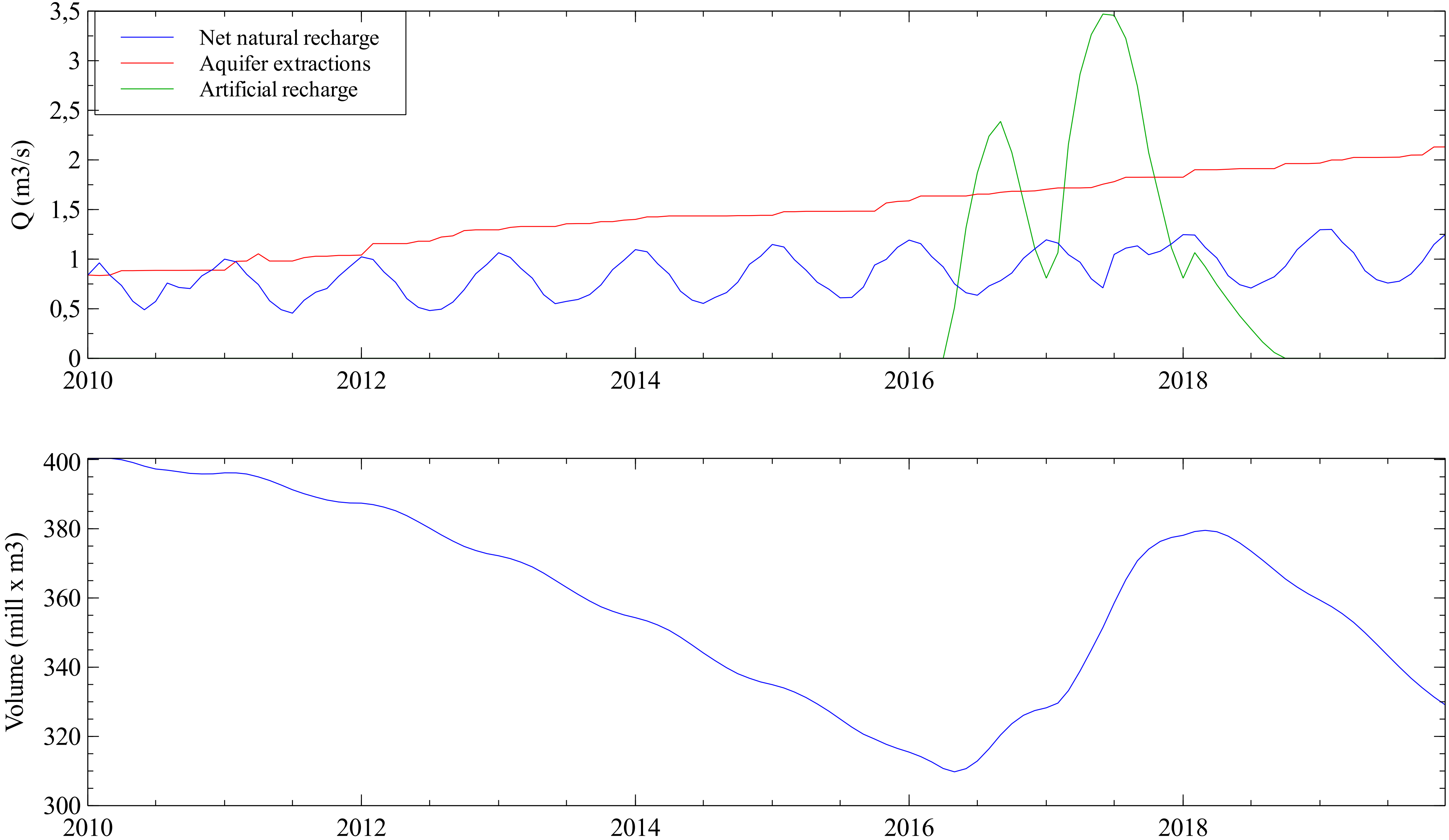
Puclaro reservoir

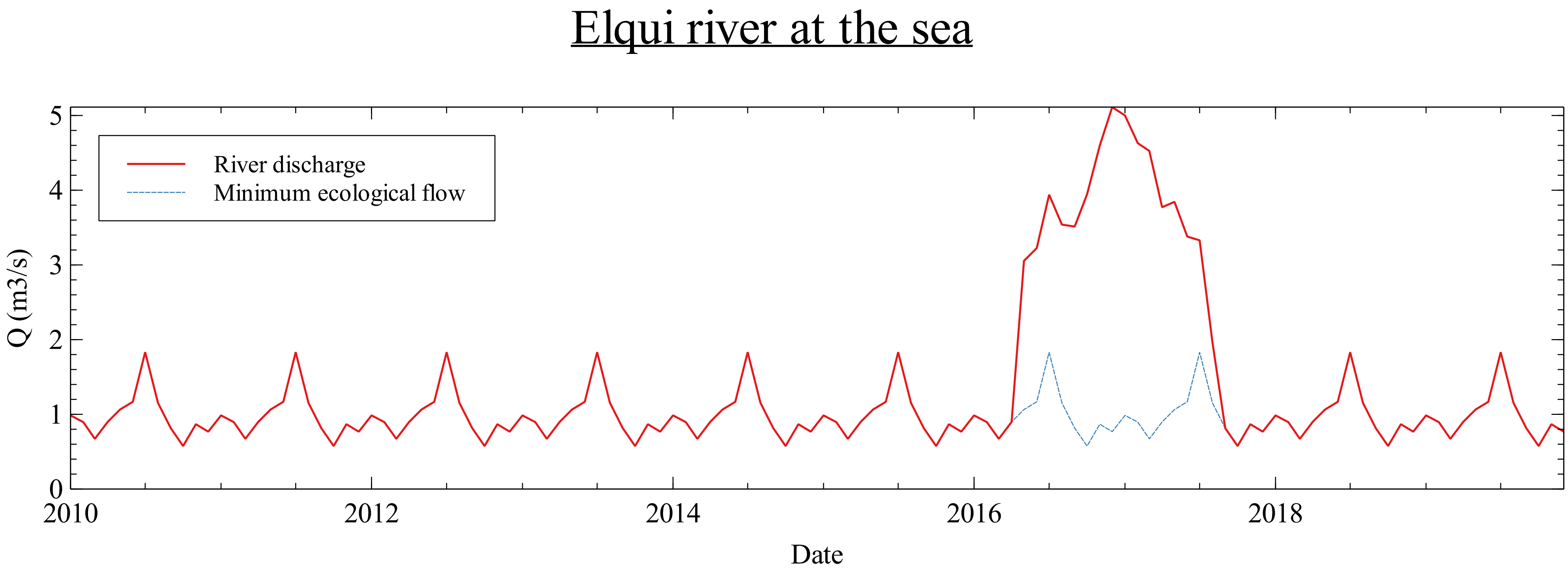


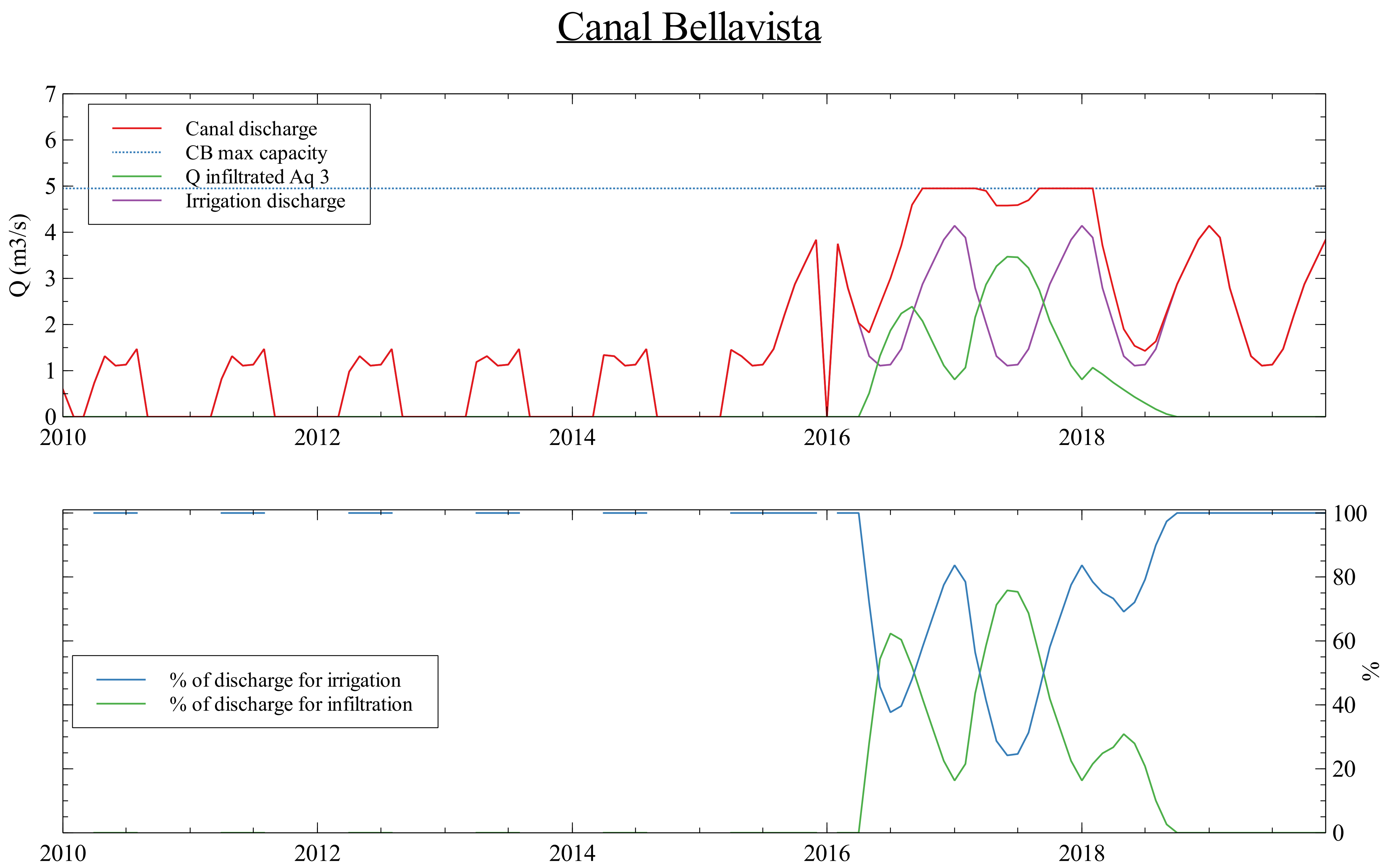
Elqui aquifer



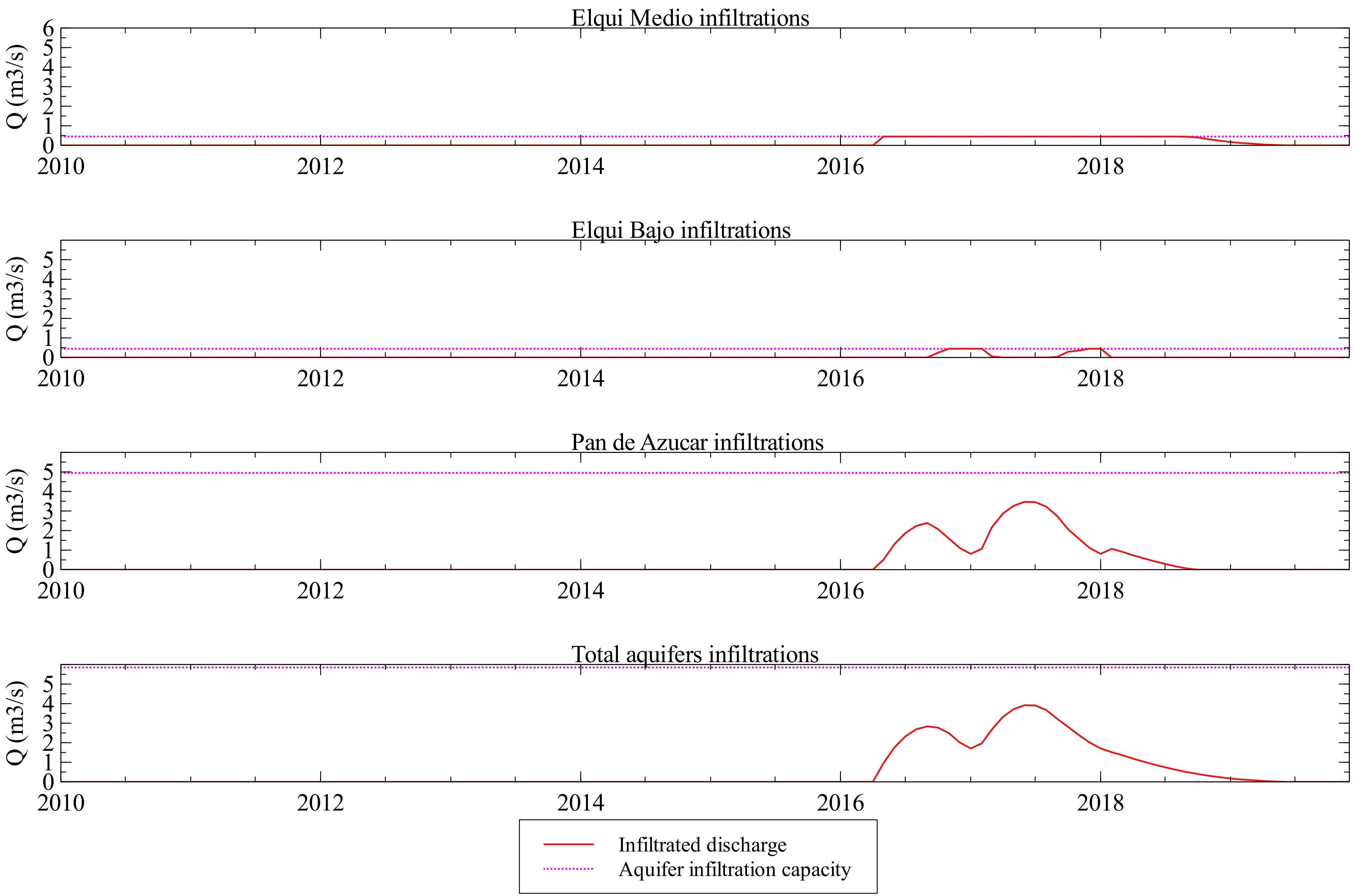
Pan de Azúcar aquifer



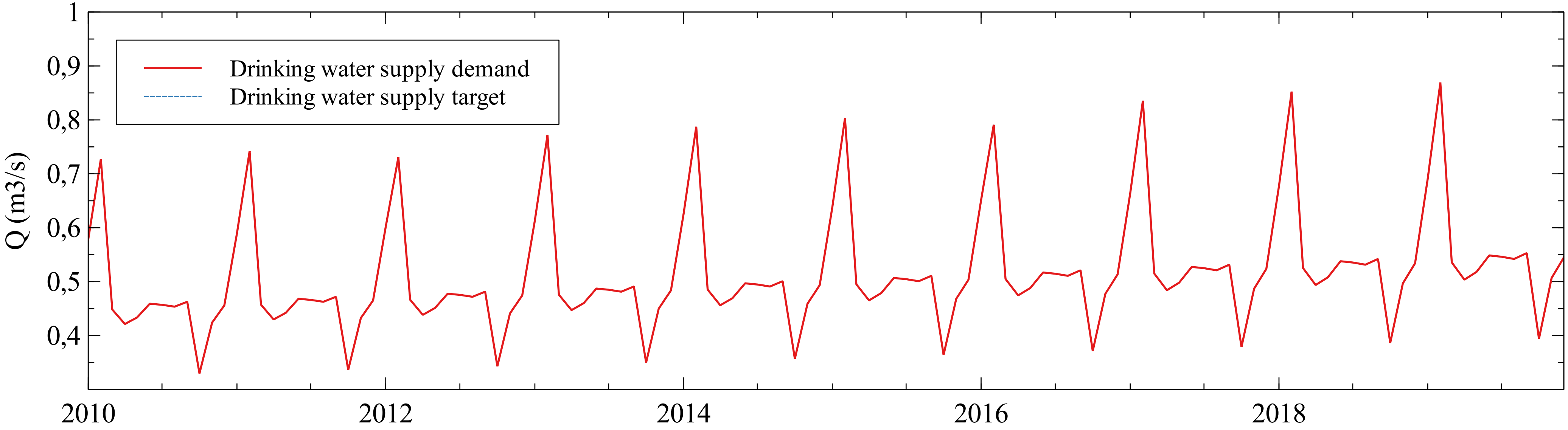

Elqui river at the sea
River discharge
Minimum ecological flow
Q (m3/s)
0
1
2
3
4
5
2010
2012
2014
2016
2018
Date


Canal Bellavista
Canal discharge
CB max capacity
Q infiltrated Aq 3
Irrigation discharge
Q (m3/s)
0
1
2
3
4
5
6
7
2010
2012
2014
2016
2018
% of discharge for irrigation
% of discharge for infiltration
%
0
20
40
60
80
100
2010
2012
2014
2016
2018

Artificial infiltration analysis

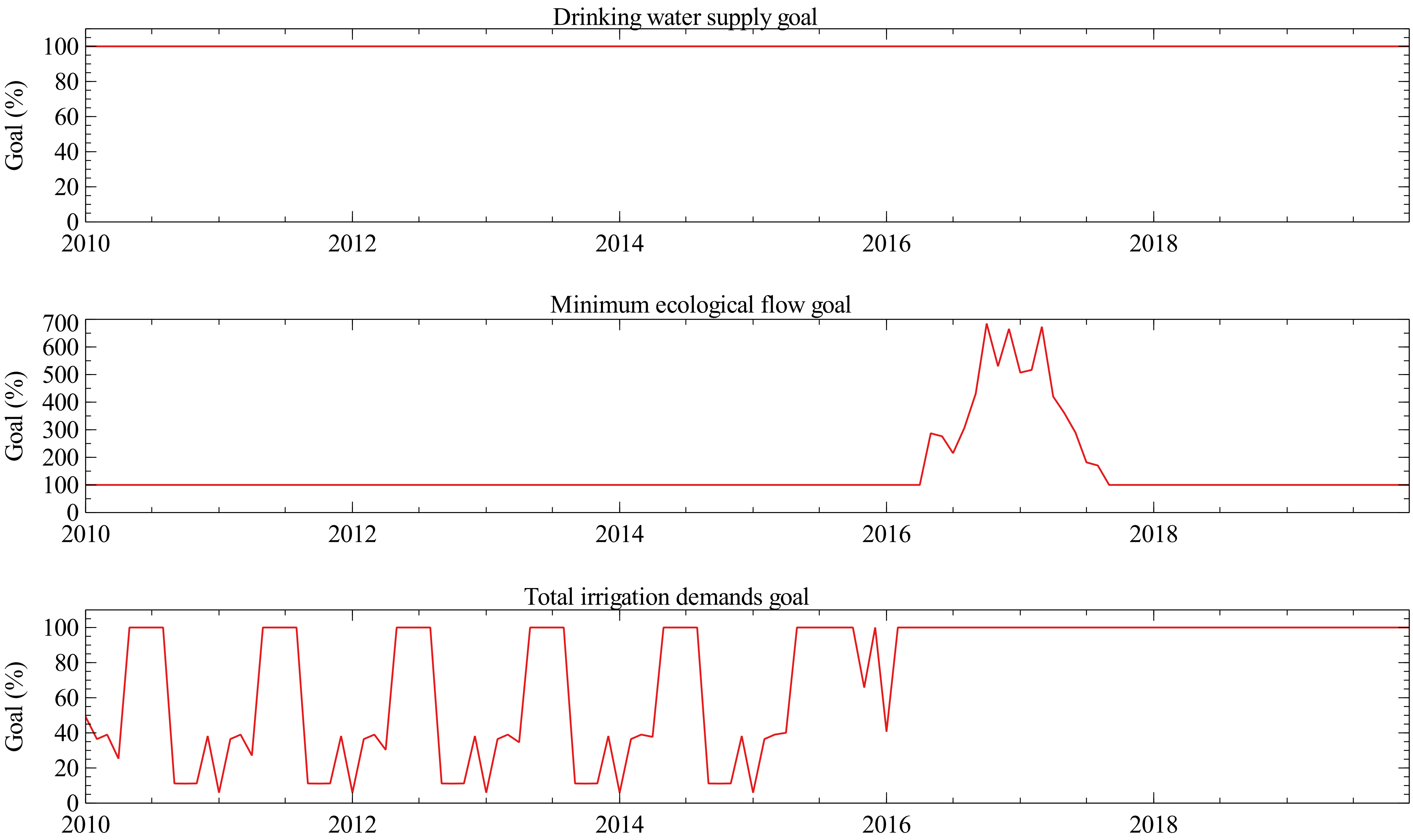


Drinking water supply



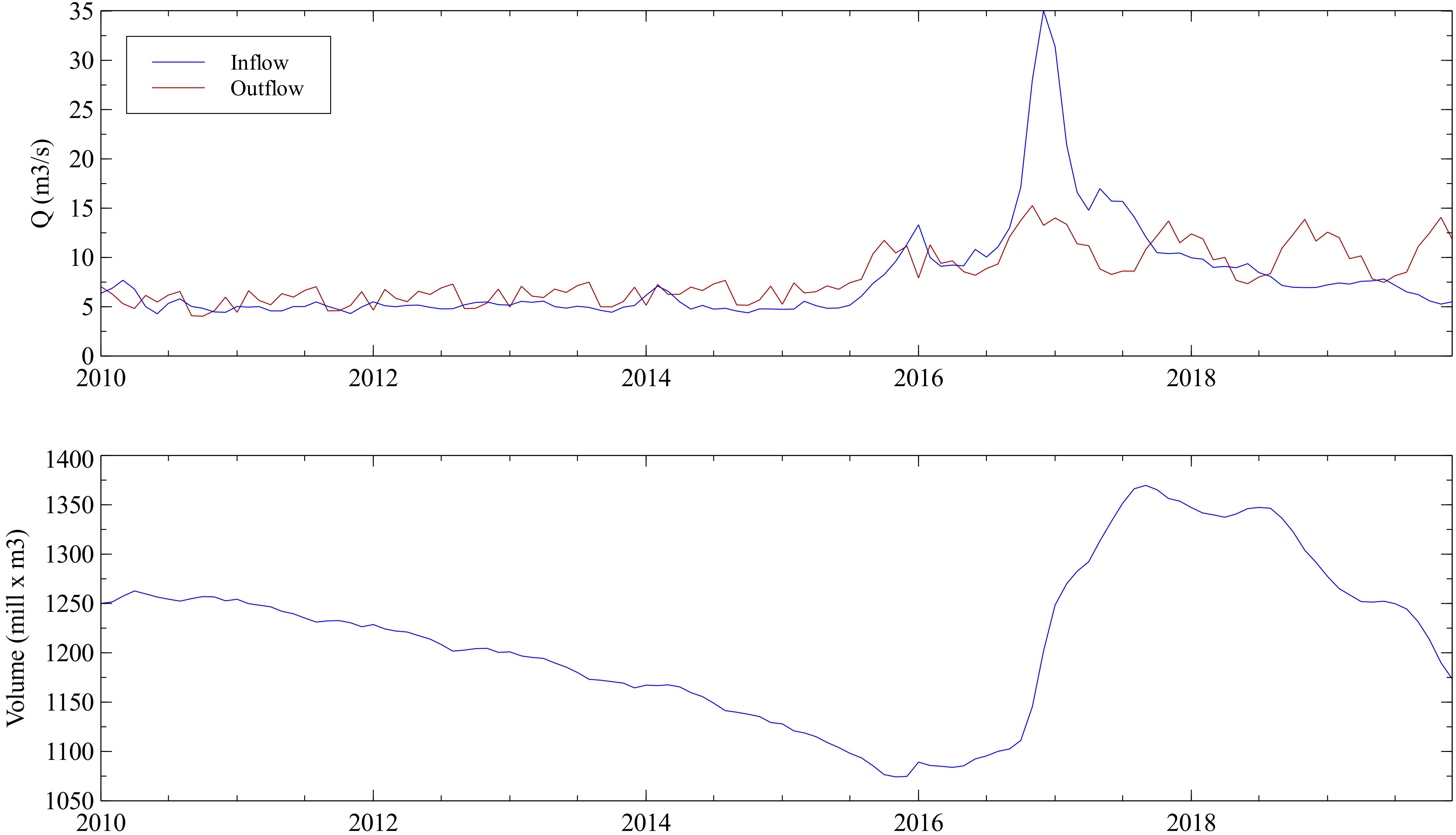
Irrigation demands analysis

Goals analysis

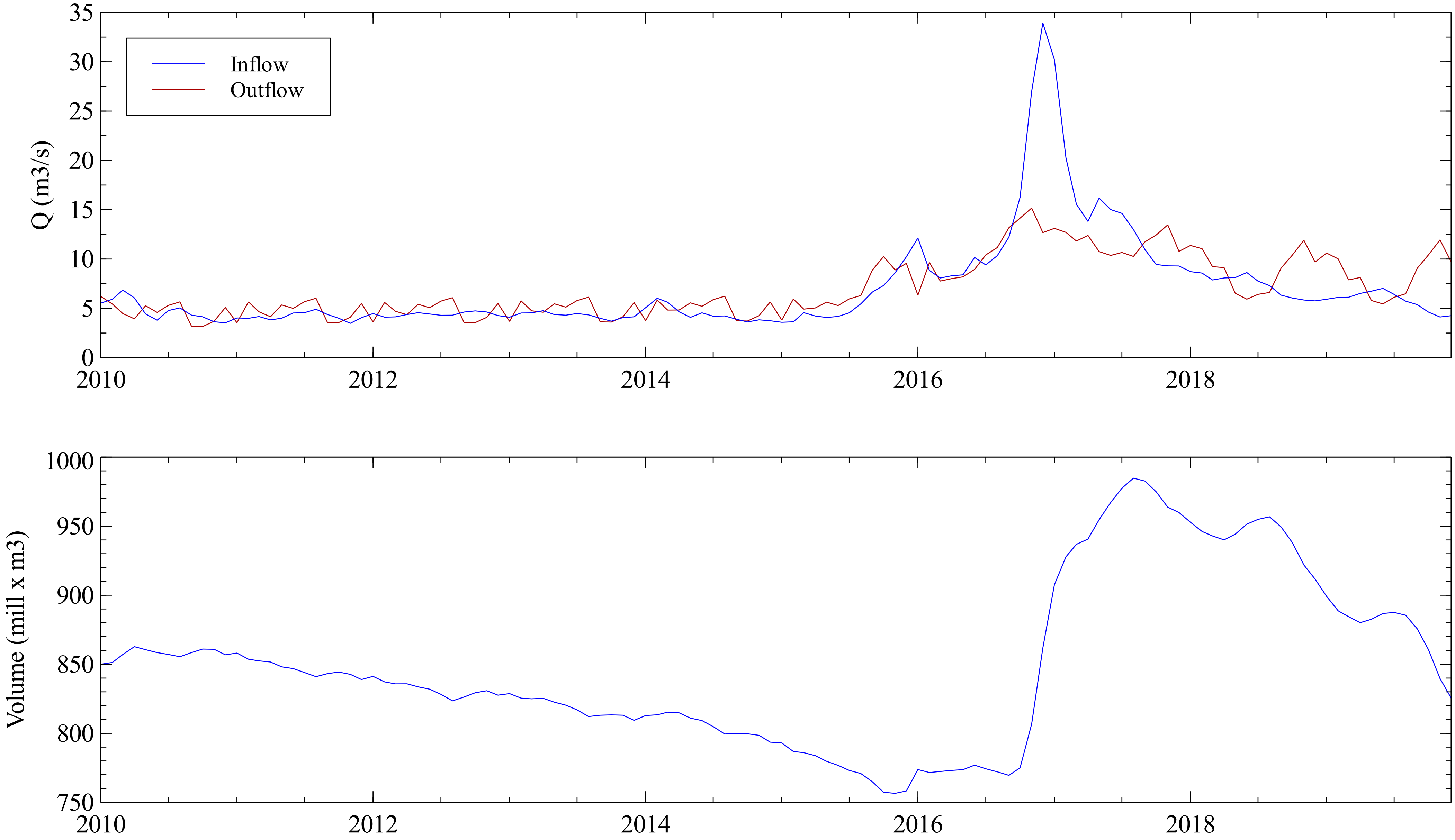


Appendix M
Scenario D

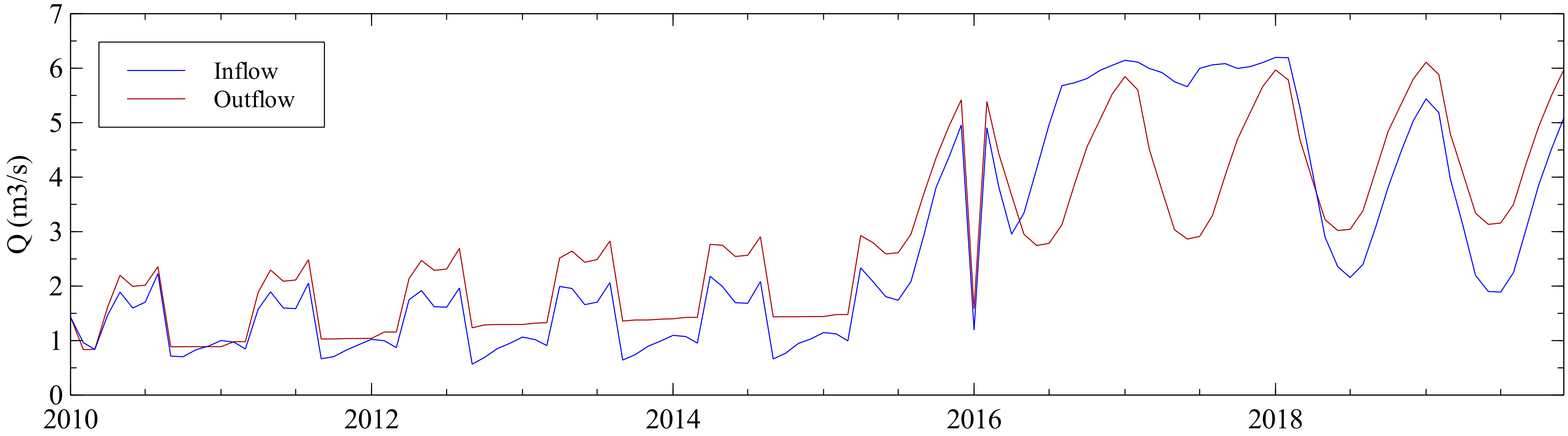
Total water balance

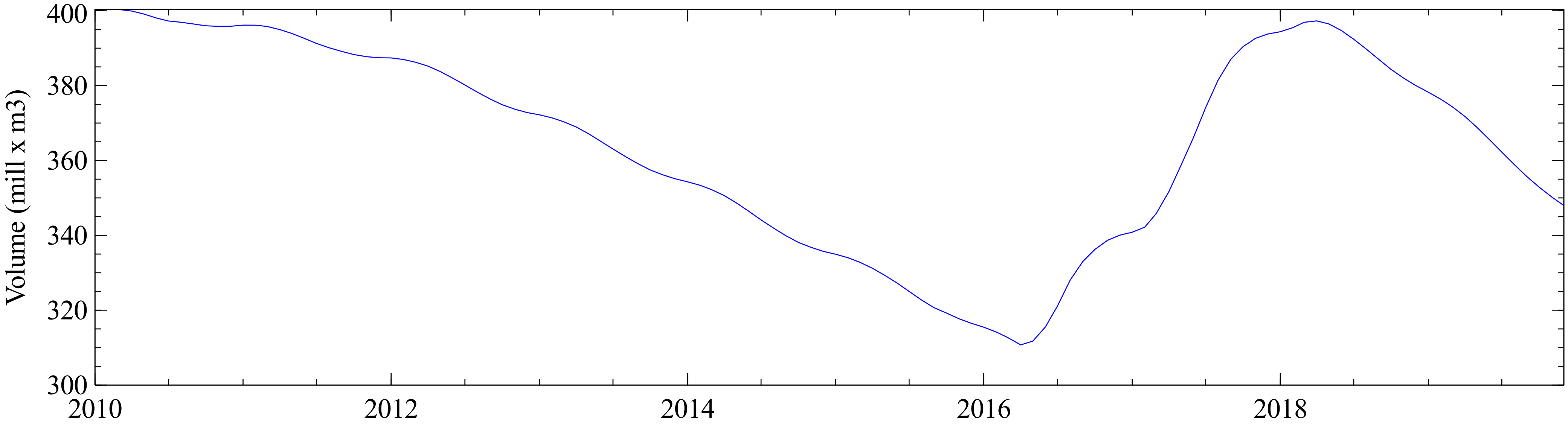


Elqui water balance

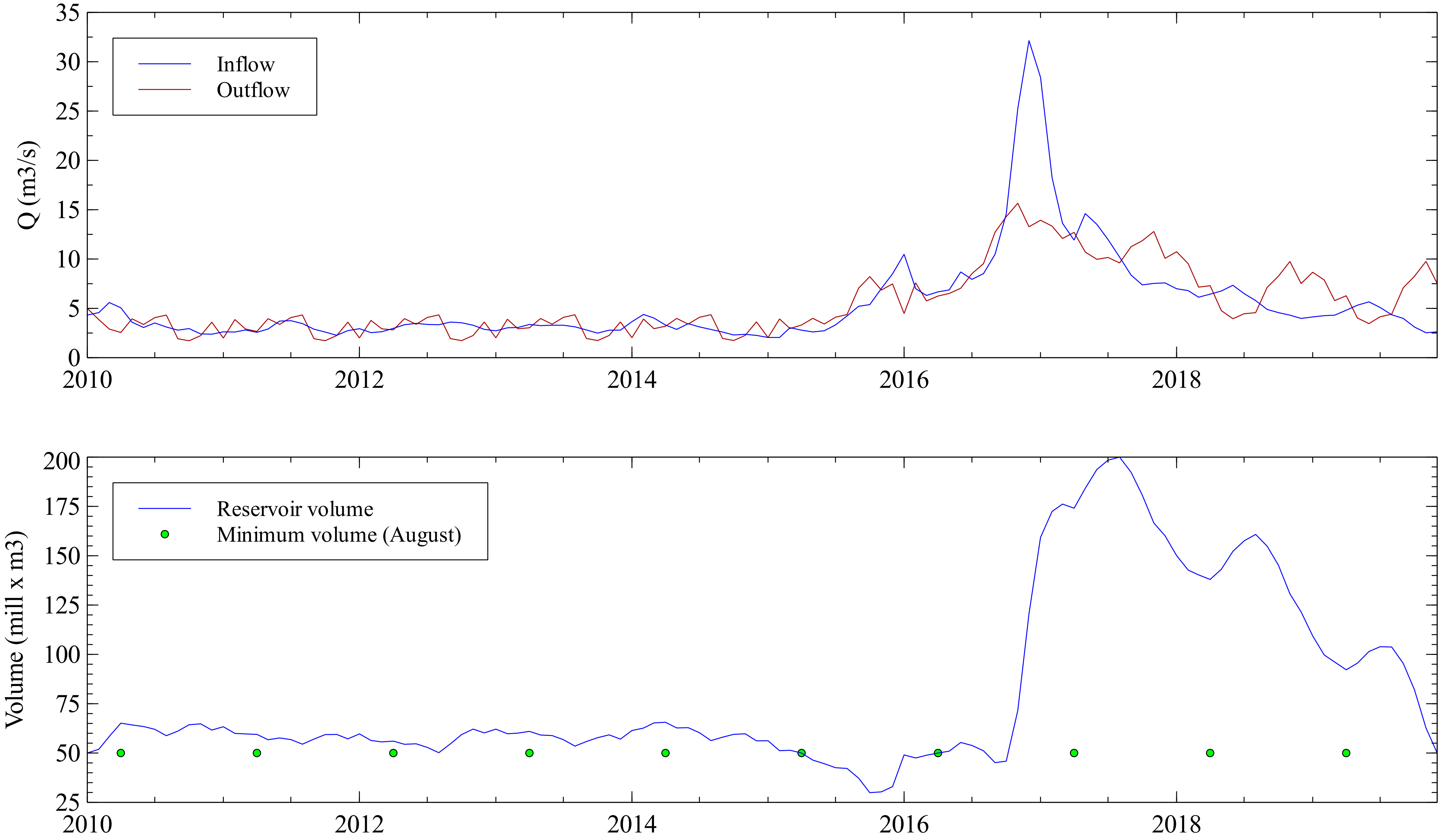


Pan de Azúcar water balance

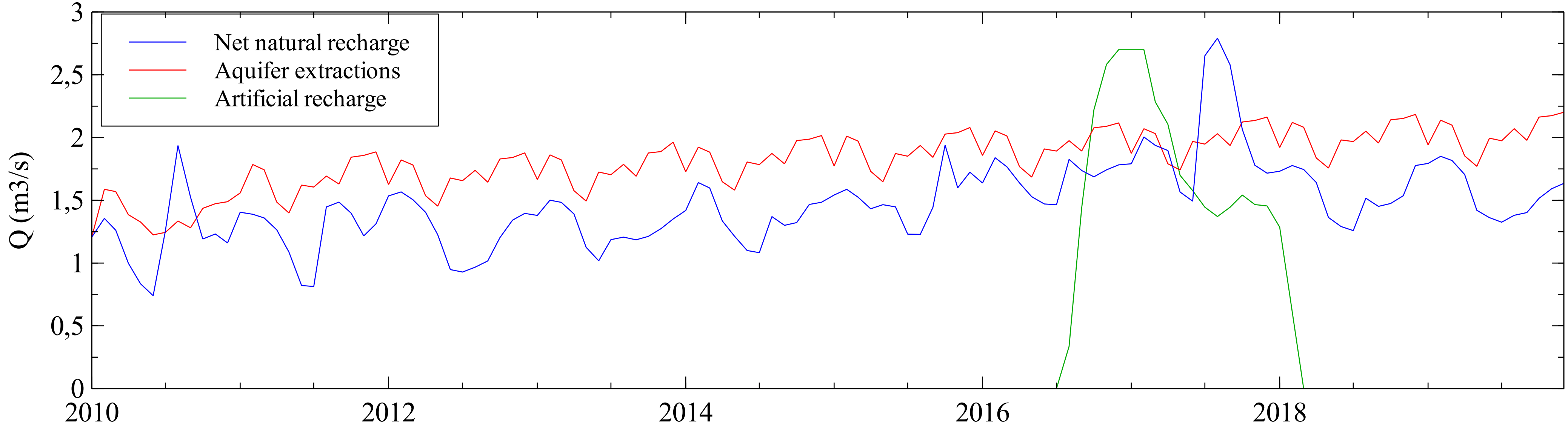


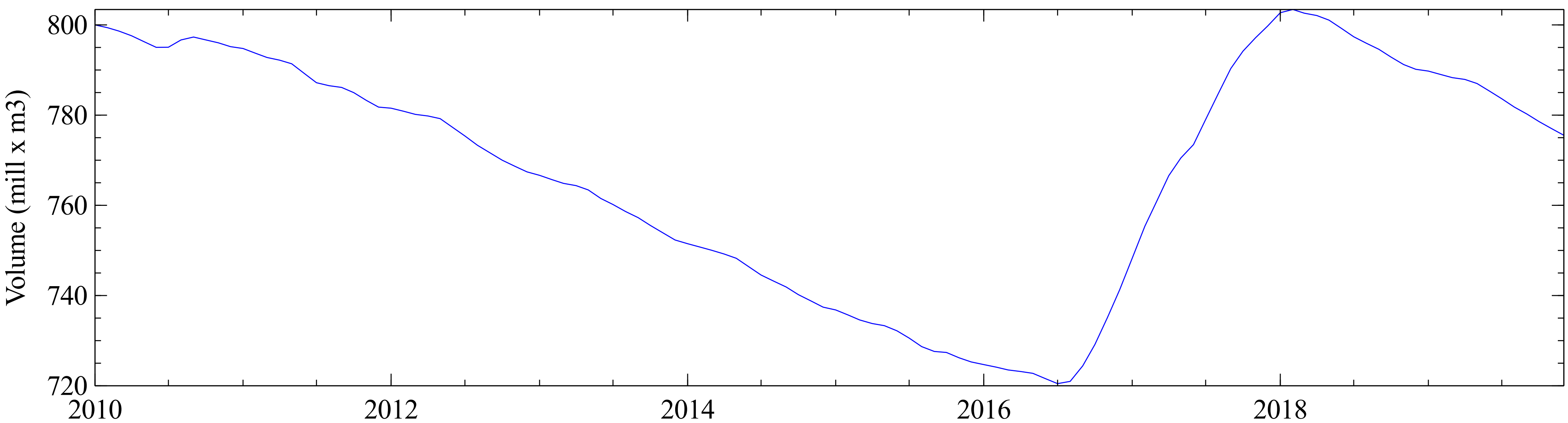


Puclaro reservoir

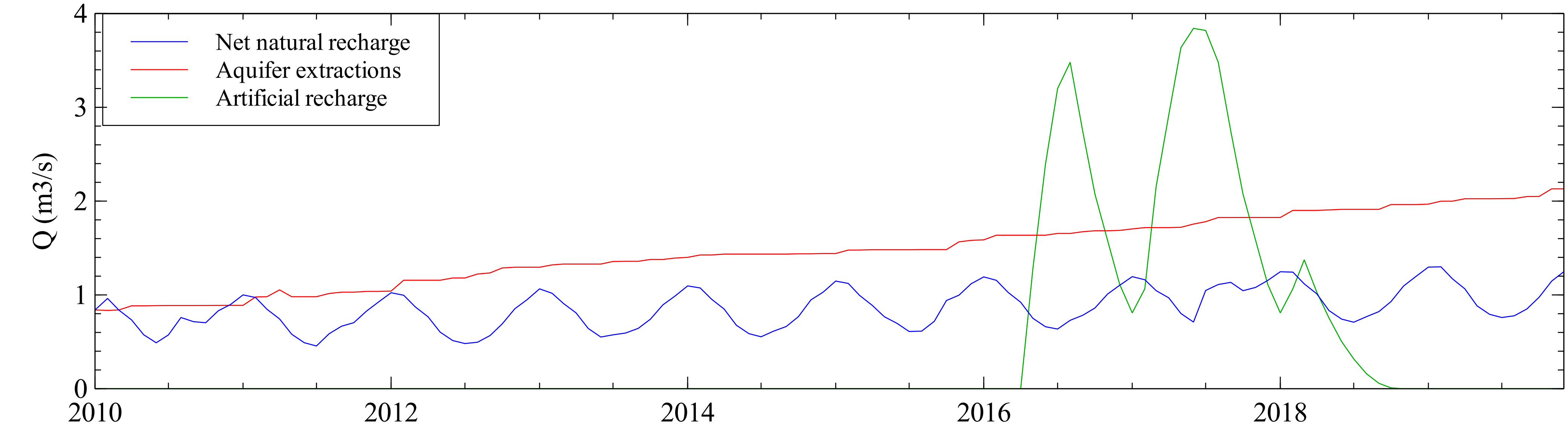


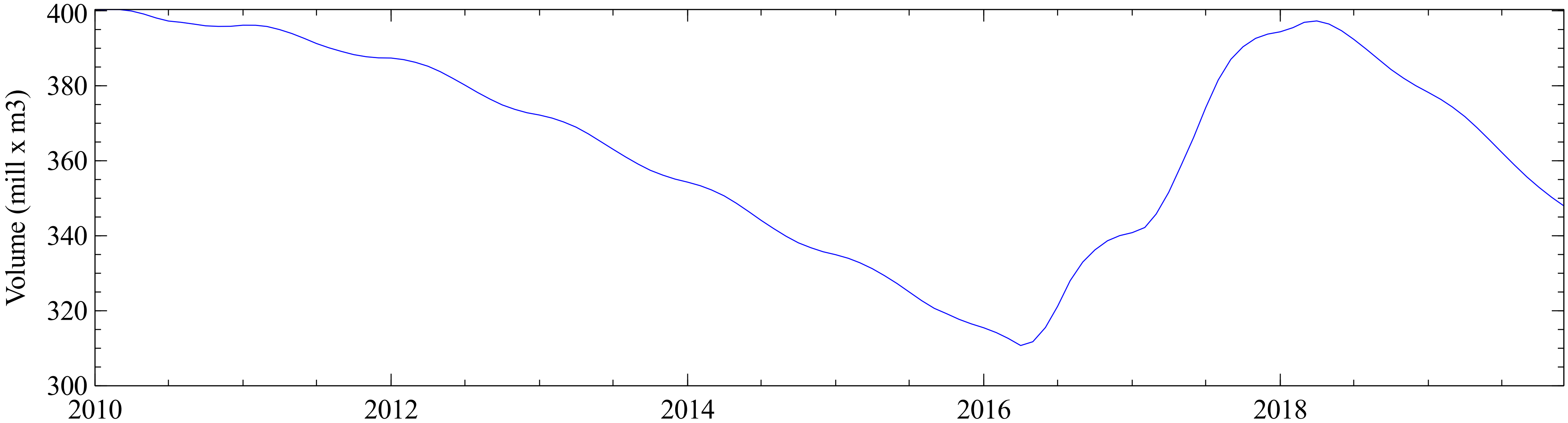
Elqui aquifer



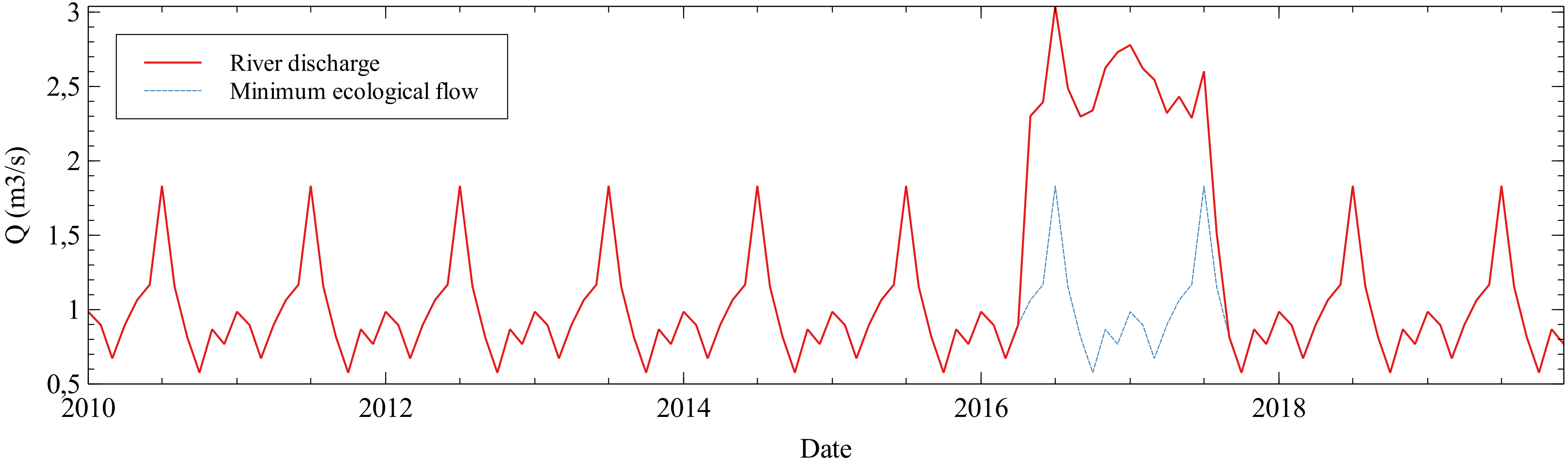


Pan de Azúcar aquifer

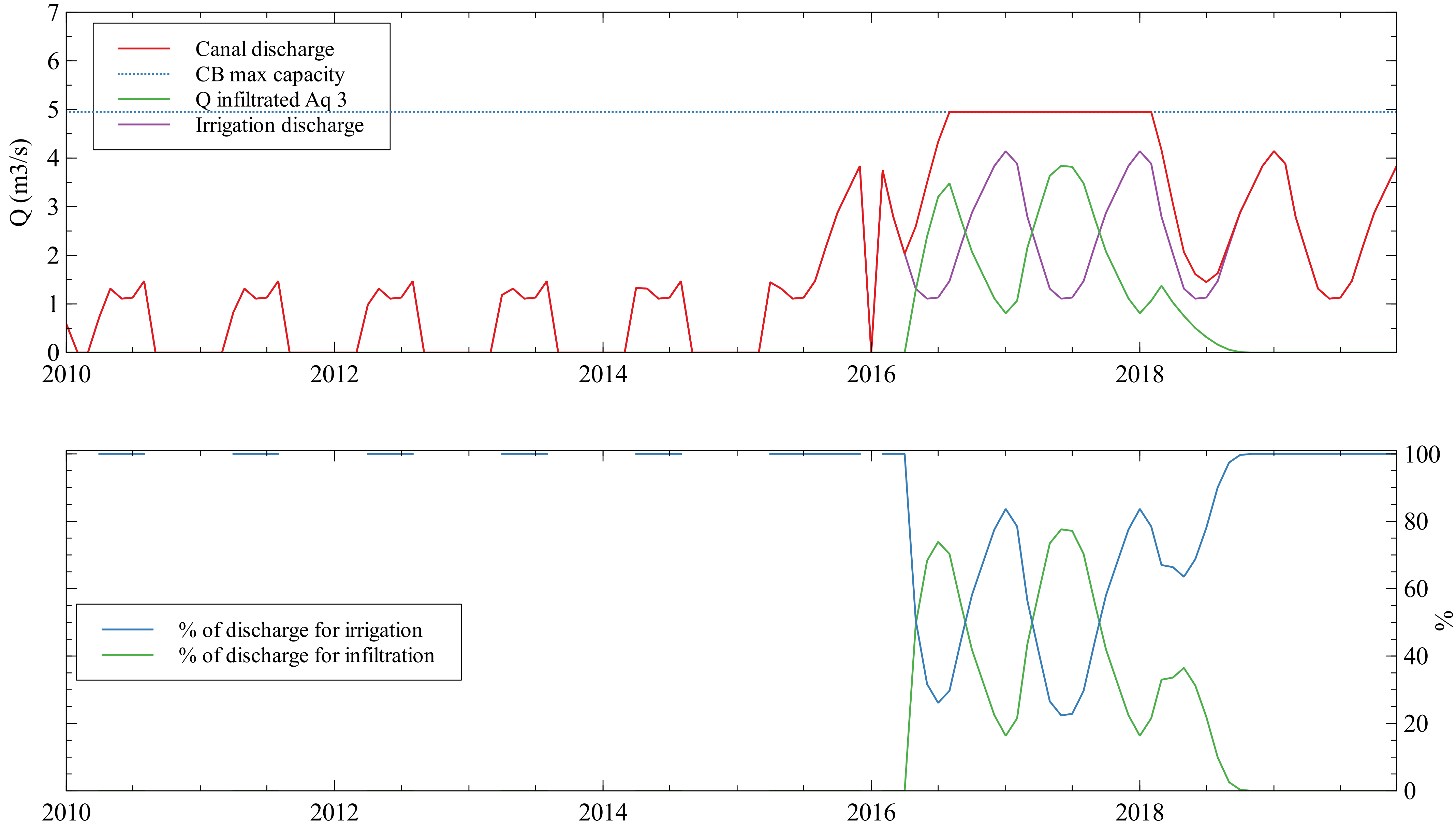




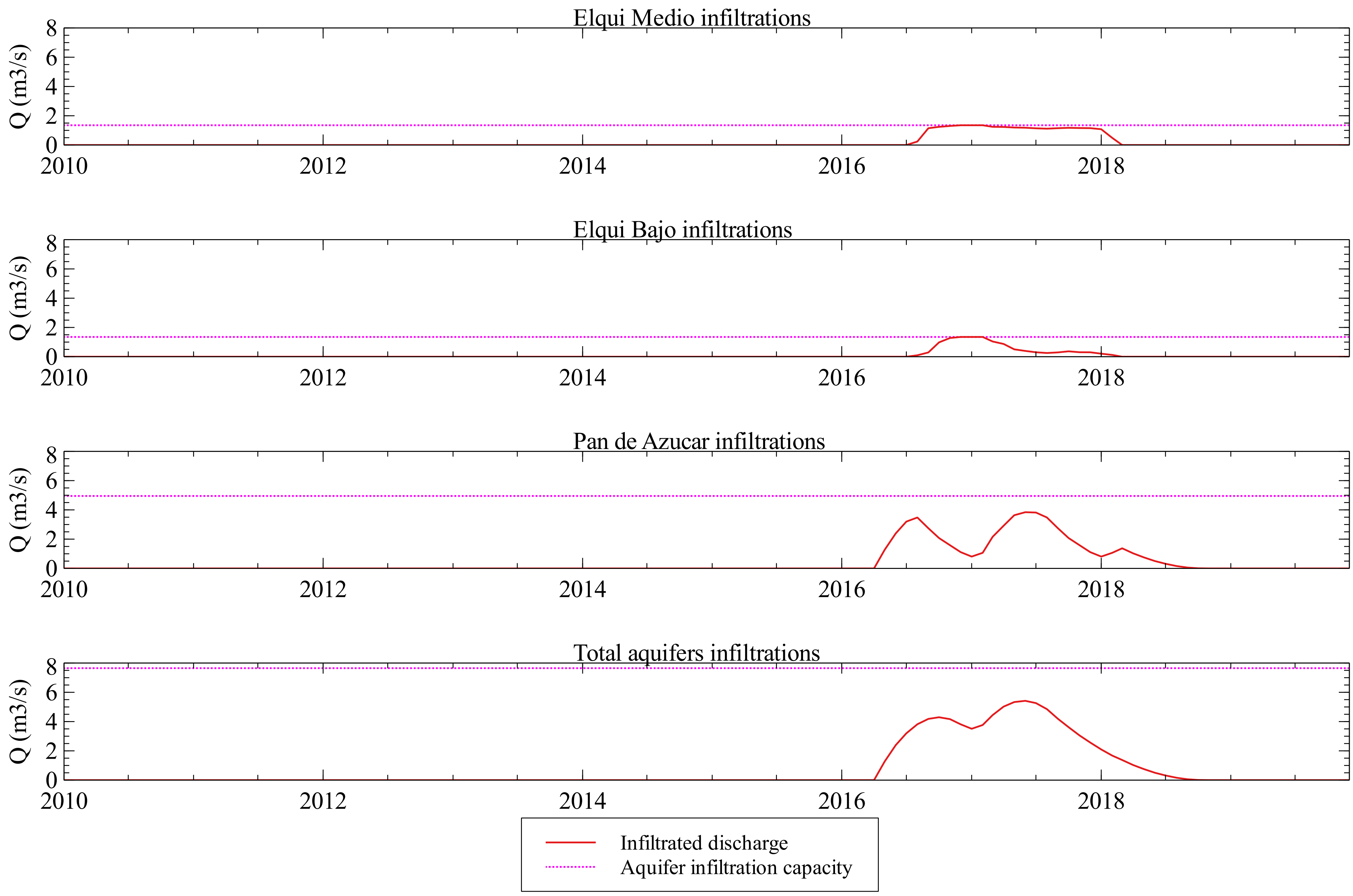
Elqui river at the sea



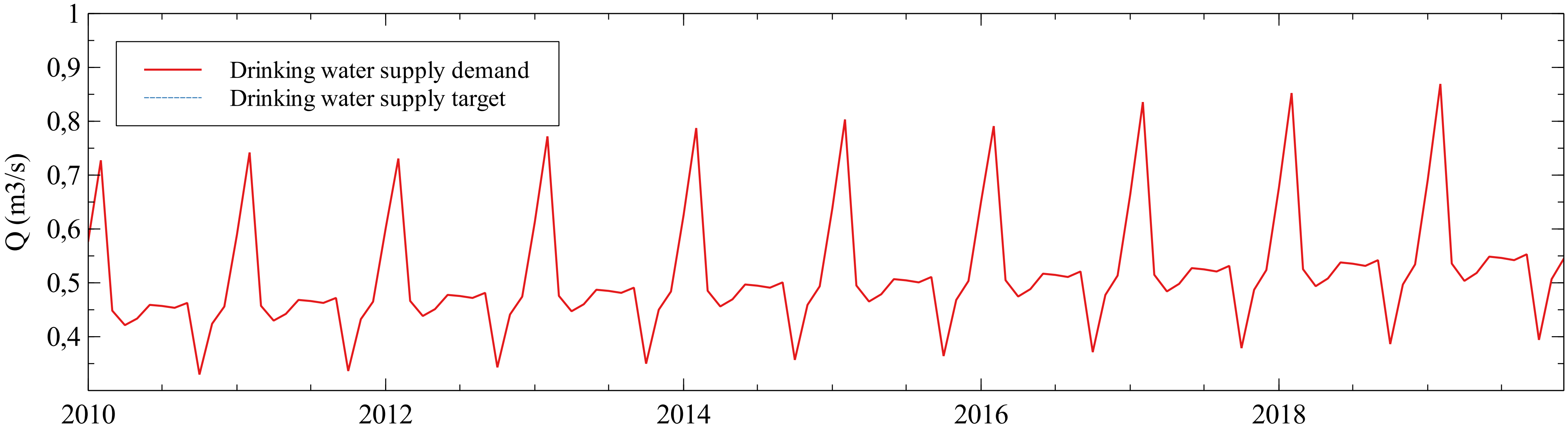
Canal Bellavista



Artificial infiltration analysis



Drinking water supply



Irrigation demands analysis

Goals analysis