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San Jacinto Geothermal Project

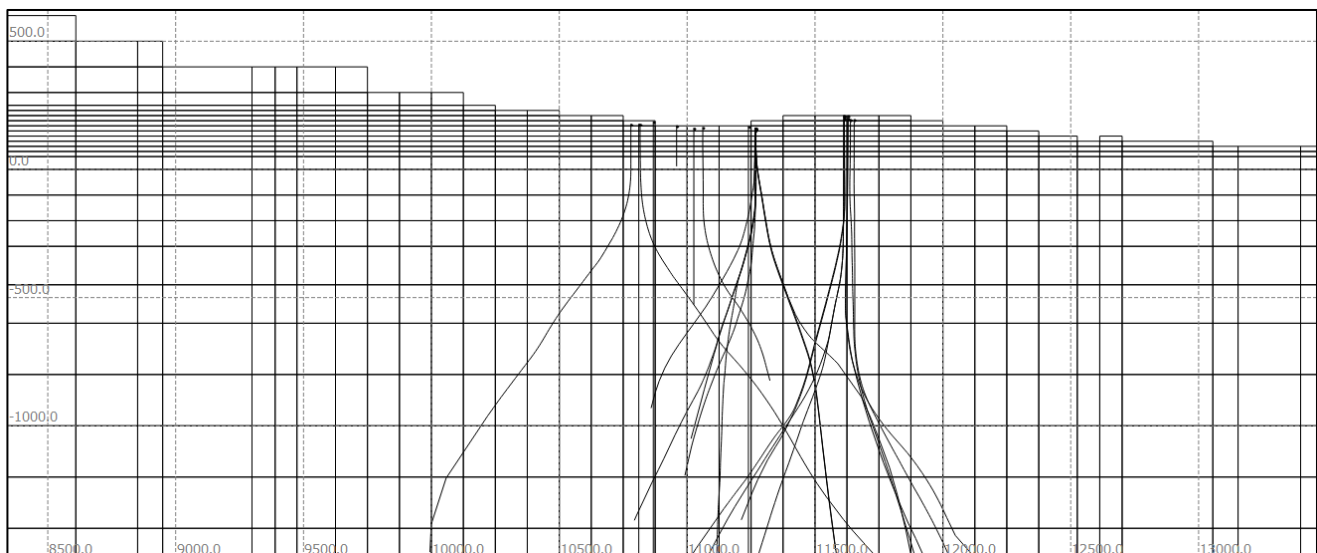
Numerical Reservoir Model Update 2019

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Executive Summary

Following the last numerical modelling of the San Jacinto geothermal resource in 2015, there has been a wide range of new information gathered, a step-up in production particularly from the SJ12 well pad, and some changes observed in resource behaviour. This information has been used to develop a comprehensive update of the San Jacinto conceptual model (Jacobs, 2019). This update plus the four further years of project operations has justified a major update to the numerical model to enhance its robustness for simulating likely reservoir behaviour in the future.

Updated Concept Model and data for constraining the model

The key elements of the updated concept model have been used to guide the development of the numerical model structure. This has included particularly the observations of general structure trends supported by observations of several phases of injection tracer tests to track fluid flows in the reservoir.

The interpreted Natural State (pre-development) temperatures have been consolidated as part of the updates to the concept model in 2017 and 2019. The original state for the new wells drilled has been interpreted. This data has been used as a first stage of calibration for the model to determine if the model can simulate this natural distribution of temperature conditions.

Summarised monthly average well production and injection data have been compiled as an input to the dynamic modelling, and the observed production enthalpy trends have been used as a key calibration parameter. Pressure trends in the reservoir cannot be directly measured and so have been interpreted from periodic surveys in wells when they have been shut in for plant maintenance. While providing a key model calibration parameter, these pressures also have some inherent uncertainty in them.

Model software and structure

As for previous models of San Jacinto, the AUTOUGH2 reservoir simulation platform was again used for this major rebuild of the San Jacinto numerical reservoir model. While the basic grid structure was retained, the model was adapted to be an air-water model, with the top surface of the model now following the topography. This removes the previous need for assumptions about the water table and allows a more accurate representation of shallow boiling.

The model covers around 340 km² and extends from the surface to an elevation of -3,200 masl. The highest resolution model blocks cover the productive part of the system and are 125 m x 125 m. The total number of blocks in the model is approximately 40,000.

A framework using the AUTOUGH2 concept of “rock types” was used to develop an entirely new permeability distribution from that previously used. This new structure is consistent with the conceptual model and has been developed for representing the subsurface “geological” features in the model.

The model is presently using a single porosity structure because this has been faster to allow the substantial iteration necessary to calibrate the model to this point, and initial runs with dual porosity achieved a slightly poorer match with enthalpy observed to date. But adaptation to the new and much faster Waiwera software will allow dual porosity to be included in the model in a next stage of modelling.

Model calibration

The model has been calibrated manually through many iterations, mainly by modification of the permeability and porosity of the “rock types” in the basic structure. But where necessary, the basic rock type structure was further modified to improve calibration. The calibration of the model was against the natural state conditions and the observed response to all production since 2015.

The calibration process is the most intensive part of the modelling exercise and careful attention to it is important for achieving model outputs that can be considered to have a sufficient level of reliability. The main observations pertaining to model calibration are as follows:

- The model has achieved a reasonably good match to the observed natural state temperature distribution in the reservoir, simulating the central upflow and outflow to the south. Calibration of the natural state has required the N-S structural grain or permeability interpreted in the concept model, but also required some barriers on the north side of the system to which are consistent with the apparent isolation of the SJ11 wells to the main production reservoir.
- Some differences between observed and modelled data exist, but typically occur where the physical processes in the reservoir are semi-stable and temperatures can vary with small changes of permeability, presenting modelling challenges but which could be improved with future iteration of the model.
- The model has been further calibrated against observed pressure and enthalpy changes in the system with generally good matches to the system behaviour under actual production.
- The model has recreated the formation of the steam zone in the upper part of the system and shown variations of enthalpy that generally follow observed trends.
- Modelling has highlighted differences in the magnitude of pressure drawdown between intermediate and deep feed levels in many wells. Deep feeds have greater drawdown in SJ6-2, 9-4, 12-2 and 12-3 in particular. This effect was not directly measurable but is supported by recent evidence of the deep feed in SJ6-2 periodically failing to sustain flow and probably is contributing to the instability of SJ6-2, 9-3 and 12-4 observed in the last 2 years.
- Well productivity (the calculation method linking predicted reservoir changes with the effect on well production) for each well has been calibrated by varying the productivity indexes for each well feed zone to simulate the observed behaviour of wells since the beginning of 2018. These have shown good matches to observed behaviour, though because they have been referenced to varying plant operating conditions, may under-predict future trends slightly.
- There is opportunity for ongoing improvement, but the model is considered sound for conducting predictive scenarios to understand the broad behaviours in the system and associated reservoir management options. Ongoing refinement will improve the ability for well-by-well behaviour modelling.

Using the model for testing reservoir response to ongoing production: Future Scenarios

Three future scenarios were investigated: continuing as present base case (001), more infield reinjection (002) and more outfield reinjection (003).

The main findings were as follows:

- The model indicates that the reservoir has now reached a semi-stable pressure balance between production and recharge from injection and other natural sources. This means that the present production rate from the field is projected to be surprisingly stable in future.
- Slow decline of enthalpy is the main factor that is projected to cause some reduction of steam flow (about 8-10% reduction) over the next decade. See Figure 1 below.
- The present model may slightly under-estimate the sensitivity of individual wells to pressure change (because it has been calibrated while the plant operating conditions have been progressively adjusted to sustain mass flow in the face of pressure decline).
- Regardless of some uncertainties about individual well behaviour, the fundamental observation of a stabilising reservoir behaviour appears sound and do not indicate any pending collapse in the ability of the reservoir to support production.
- Comparing the options of more (scenario 002) or less (scenario 003) injection within the central area of the reservoir has shown that over the next 10 years the benefits of pressure support from infield reinjection are forecast to outweigh negative cooling effects:

- The model forecasts that the infield reinjection scenario 002 produces the most steam over the next 10 years with approximately 40 t/hr more than the base case 001 and approximately 60 t/hr more than the outfield reinjection scenario 003.
- The infield reinjection wells are forecast to provide deep pressure support with only a very small negative impact on the shallow production steam zone.
- Less infield injection does not have a major impact on stimulating the expansion of the high enthalpy “steam zone” that has helped boost production from SJ4-1
- Longer term, greater infield injection has a negative impact on enthalpy, and the present single porosity model probably under-predicts this cooling effect. More work on the model and field management is required to optimise infield reinjection to reduce the cooling impacts over the long term.

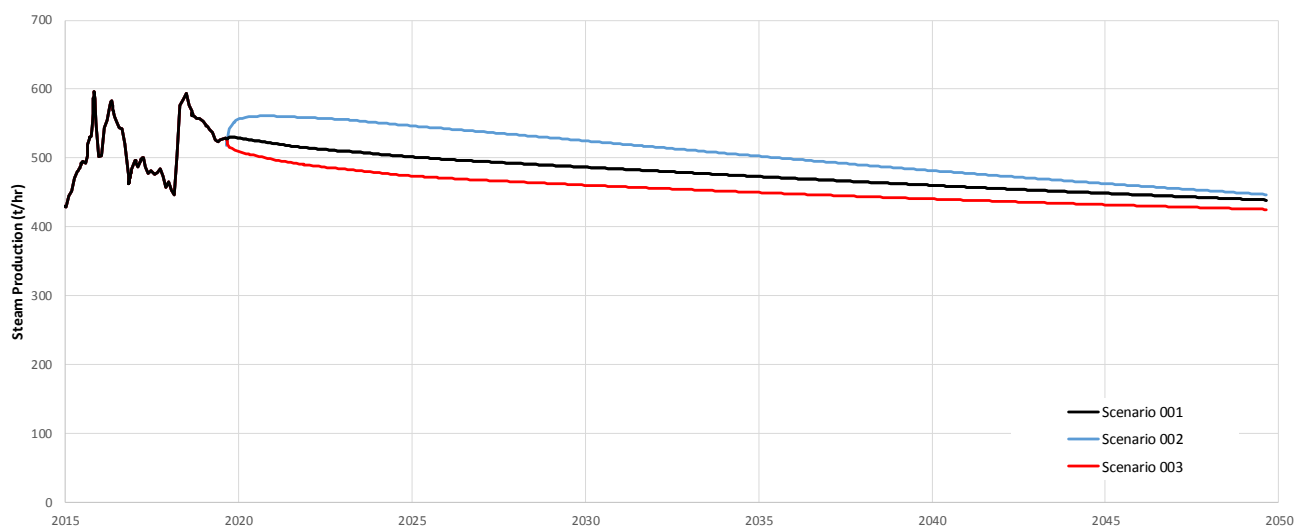


Figure 1: Comparison of model forecasts of total steam production over all of production wells for the three scenarios. Scenario 001 is the present approach to injection and assuming no make-up wells. Scenario 002 assumes greater injection near the production field, and Scenario 003 assumes less injection in the central area.

Conclusions

- The San Jacinto field has had considerable pressure drawdown since 2015 but the observed pressure trends and the model indicate semi-stabilisation of pressure in future.
- While some wells (SJ6-2, SJ9-3, SJ12-4) have recently proven to be unstable under the declined pressure, and when they go off line can make substantial impact on production, the model indicates that this situation is not on the verge of a major failure. The model has provided some insights into the pressure changes at different depths in the system that have led to this well sensitivity, particularly the decline of the deeper feed in SJ6-2.
- Sustaining production will require ongoing management of the operating conditions of individual wells, securing some additional supply from localised opportunities such as the intermediate depth steam zone, and careful management of injection.
- Pursuing some deep pressure support from infield injection seems a prudent course of action to try and realise some of the gains predicted by modelling, but any injection wells that have high risk of creating early cooling (as evidenced by tracer returns particularly) should be used with caution.
- Optimisation of reinjection and production can be supported by investigating more scenarios using the present model but also following the recommended model refinement and conversion to dual porosity.

- The difference in well performance between the scenarios indicates how sensitive the present well production is to the magnitude and balance of mass extraction and injection. Reducing in-field injection (comparing scenarios 001 and 003) has a negative impact on production. Similarly adding additional mass extraction (such as from additional drilling) would be expected to have a similar impact on reservoir pressure and would reduce the flow of existing wells. Additional mass extraction could also further destabilise the wells that have recently been sensitive to deep feed pressure drawdown and cause some wells to be “Off line” for longer periods.
- Despite the present stability, the reservoir is not obviously under-producing, and considerable caution should be used in considering any make up well drilling to increase production rates. Past drilling has boosted production in the short term, but stabilised to lower levels than initially. Our conclusion based on present scenarios is that it is probably more valuable to consider optimisations such as tapping shallow steam layers; possible workovers or stimulations of existing wells in response to changing feed pressures; and managing injection.
- The model now has reached a level of detail and calibration, that with review of detailed behaviours in both the model and wells, plus some additional calibration and conversion to dual porosity, should be sound for more detailed evaluation of well-by-well behaviour.

Important note about your report

The sole purpose of this report and the associated services performed by Jacobs is to report the results of update to the San Jacinto numerical model in accordance with the scope of services set out in the contract between Jacobs and Polaris Energy Nicaragua SA (PENSA). That scope of services, as described in this report, was developed with PENSA.

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1. Introduction

1.1 Background

The San Jacinto numerical reservoir model was last updated in 2015 and incorporated new well and resource monitoring data up to that time. The model update resulted in a calibrated numerical model that provided a good representation of the San Jacinto resource and provided an estimation of future reservoir response to continued production and injection (Jacobs, 2015).

Following the 2015 model update there has been a wide range of new information gathered, a step-up in production particularly from the SJ12 well pad, and some changes in resource behaviour. This information has been used to develop a comprehensive update of the San Jacinto conceptual model (Jacobs, 2019). This update plus four further years of project operations has justified a major update to the numerical model to enhance its robustness for simulating likely reservoir behaviour in the future. The major new information that has been incorporated in to the updated reservoir model includes:

- The results of a make-up drilling campaign (SJ6-3, SJ14-1 and SJ9-4) in late 2015 plus a remediation and acid stimulation programme to enhance injection well performance (SJ1-1, SJ10-1, SJ11-1 and SJ12-1 ST1).
- The results of a range of new field studies conducted in early 2017. The main objective of this work was to assess how the San Jacinto resource has changed under an increased level of production and over time. This includes the evolution of a two-phase/steam zone in response to drawdown and boiling of the deep reservoir. An updated conceptual model incorporating the results of this work was used to help inform the most recent make-up drilling strategy which was completed in January 2018.
- New drilling and testing results for wells drilled during 2017, including a new injection well (SJ11-2) and three new production wells (SJ4-2, SJ12-4 and SJ12-5).
- Well production and injection performance history since the 2015 reservoir model update, including a large step-up in production from Pad 12.
- Reinterpreted reservoir pressure and temperature history of the San Jacinto reservoir system that was developed for the 2018 model update.

While previous models were probably useful for testing major changes, the recent work done to update the concept model of the field has highlighted many processes happening in the system, including major recharge from the south and an evolving steam zone within the central production borefield. This has highlighted how the surrounding areas to the main production field and the connectivity to the reservoir are very important in controlling reservoir behaviour. The model update needed to be substantial to reflect these reservoir processes.

1.2 Objectives of the Model Update

The main objective of this model update is to establish a numerical model that reasonably represents the current conceptual understanding of the San Jacinto geothermal resource and its observed behaviour over the time that the project has been operating. The establishment of a suitably robust model can then be used with confidence to test the expected effects of reservoir management options such as changed extraction rates, changed injection locations, attempts to get the upper reservoir to “boil” or produce more “dry” steam, or effects of reduced injection temperature. The model would be used to test field management approaches to optimising production/injection in the near and long-term through modifications to existing operating conditions, by the drilling of make-up wells, or a combination of both. The model can also later be used to test changes on the supply of brine to any potential binary plant development, and the expected effect of cooler brine on field performance.

2. Updated Conceptual Model

In 2018-19 Jacobs prepared a comprehensive update to the conceptual model of the San Jacinto Geothermal Field, which incorporated the data accumulated during the years of operation and make-up drilling since 2012. The current update is an incremental one, and incorporates new knowledge gathered since 2017 (Jacobs, 2019). This update has been used to guide the numerical reservoir model update and the key aspects pertaining to the model framework are summarized in Section 4.

There have been two changes over the past few years that are particularly significant to our understanding of the behavior of the field and the potential implications for future field management strategies:

1. Faulting. The evolution in the structural model has significant implications for the nature and distribution of permeability within the production field. It suggests that the earlier approach of targeting specific structures within the production field is less likely to deliver higher rates of drilling success. However, while we generally agree that there are not as many discrete through-going fault targets within the field as previously thought, there is still reservoir evidence for the presence of some such structures and the current numerical modelling may help shed some light on this subject. Our understanding of this aspect of the field is currently evolving and warrants further investigation and discussion between PENZA and Jacobs personnel as it will be significant to planning future drilling campaigns and for the refinement of field management strategies.

2. Steam Zones. The development of steam zones in the central production field is an important change in the field since the previous report and has significant commercial implications.

An extensive deep drilling campaign starting in 2010 and the subsequent step change in production level from 10 MWe to 72 MWe ultimately caused reservoir pressure decline, increased boiling and development of steam zones. It has also seen increased steam production in several wells (SJ4-1, SJ9-3, SJ12-3). With the commissioning of injection well SJ11-2 in the north (August 2017) and a reduction in injection to the south (SJ1-1 and SJ10-1), there was less cooling in the south and a rise in the temperature of the fluids being drawn back into the central production area, thereby further stimulating boiling and steam zone expansion. Diminishing injection returns were observed from the south and consequently SJ10-1 was closed completely in June 2018 with the intention of maintaining this trend. In April 2019 PENZA took a decision to resume injection into SJ10-1 but this was stopped 3 months later due to indications that it was impacting the production area and could also adversely affect ongoing steam zone evolution.

The shallow steam zone is divided into three distinct horizons, as shown in Figure 2:

- Upper Steam Horizon (~180°C, ~10 bar) at ~50-160 mVD and underlying pads SJ4, SJ6, SJ8, SJ9, and recently SJ12. It consists of multiple isolated lenses of steam at varying depths.
- Intermediate Steam Horizon (~205°C, ~18 bar) at ~200-300 mVD and underlying pads SJ3, SJ4, SJ6, SJ8, and SJ9. It appears to be a single broad interconnected steam zone.
- Lower Steam Horizon (~226-236°C, ~25-30 bars at ~500-700 mVD and underlying pads SJ4, and SJ9. It is a single steam zone contiguous with the underlying liquid reservoir

While the steam zone is now successfully expanding, with the desired result of increasing MWe production from the central production area, it has also caused an increase in steam-driven surface activity, posing a risk to safety and infrastructure. Efforts are ongoing to monitor changes in surface activity and to develop a plan to address it. The details are covered in the Assessment of Shallow Steam Activity report completed by Jacobs (2018).

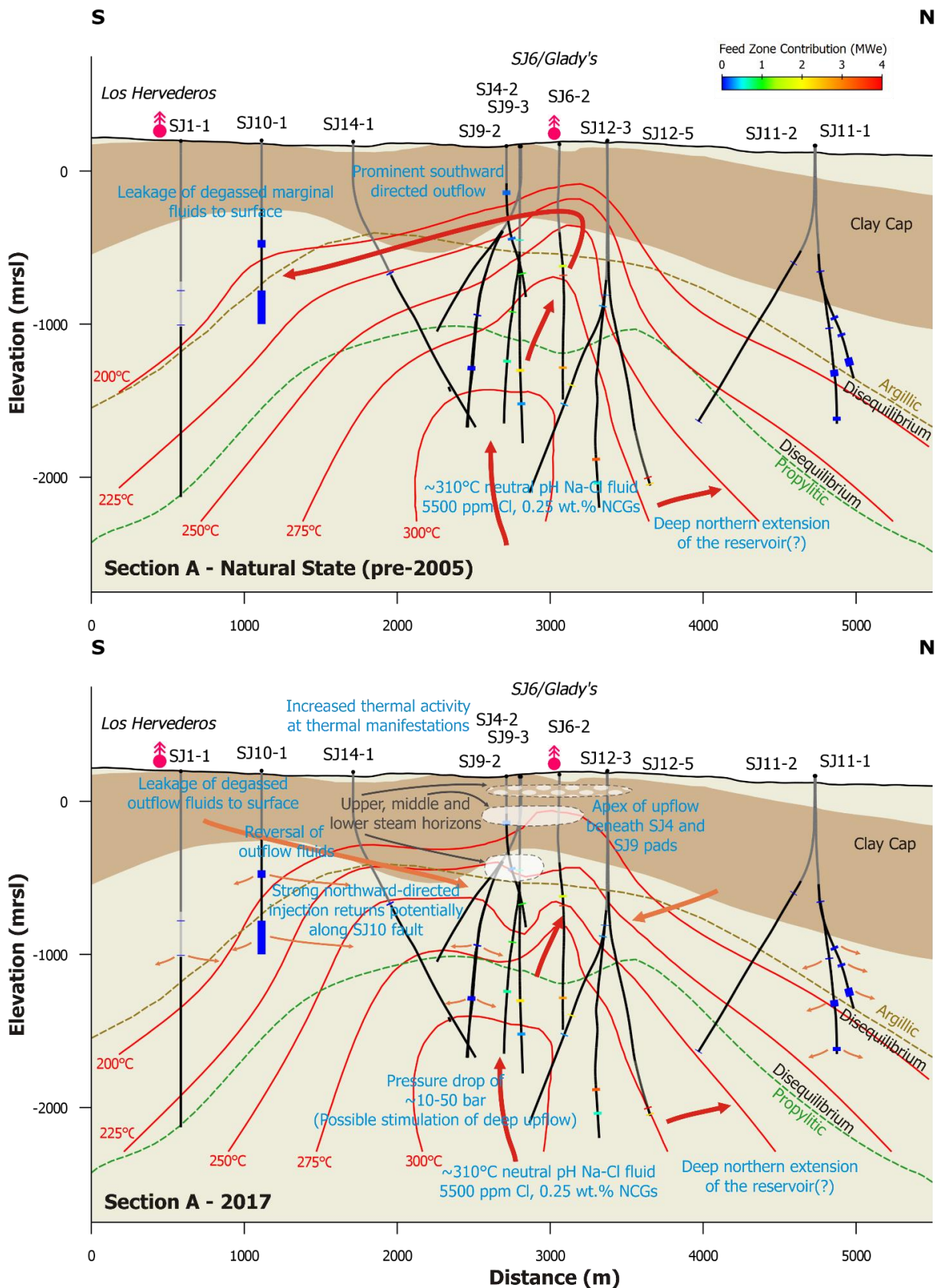


Figure 2: N-S cross-section through the natural state and 2018 conceptual models for San Jacinto.

2.1 Natural State Conditions

A key part of the concept model that is used to calibrate the numerical model has been the interpretation of the original temperature and pressure conditions such as those indicated in the cross section of Figure 2. These form the first main calibration for the model: to match the observed original temperature distribution across the field as seen in actual drilled wells.

The challenge is that the well itself impacts the temperature and pressures measured by PT logs such as by allowing internal flows, having boiling and steam accumulation in upper levels, temperature not being stabilised after drilling (or an early discharge) and pressures are dominated by the major permeable zone and pressures in cased off aquifers cannot be directly measured. This means that the PT logs collected through the early stages of a well's life have to be interpreted to determine likely actual reservoir conditions.

In addition, many new wells have been drilled since production initially started in 2005 and what they find may be affected by the history of production, but such new wells still add valuable insights to the original conditions and need to be interpreted in terms of an assumed natural state condition.

This interpretation of natural state conditions was described in Section 5.1 of the Concept Model Update report (ZP00955-RPT-DR-045, 19 June 2019), and with details of how logs were interpreted in the Appendix A.

The baseline and interpreted temperature profiles for the wells drilled to date is provided in Figure 3. The temperature profiles for the most recently drilled production wells, SJ12-4 and SJ12-5, confirmed the north-east extension of the deep hot reservoir and increased the overall area of productive resource. The temperature profiles for the wells that have been drilled to the south-east part of the production area (SJ6-2, SJ9-3 and SJ12-3) are consistent with the conceptual understanding of the deep system upflow in that part of the resource. The temperature reversal in SJ6-3 provides an indication that this well intersects the western margin of the reservoir. Temperature reversals in SJ3-1 and SJ6-1 also provide an indication that these wells are situated close to the western margin of the San Jacinto-Tizate sector. The most recently drilled injection well SJ11-2 had relatively hotter fluid temperatures than SJ11-1. This is likely due to its closer proximity to the production borefield.

The PENSA team have indicated they may have different interpretations for some wells, and so these should be discussed in more detail.

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SJ Wells Temperature Profiles

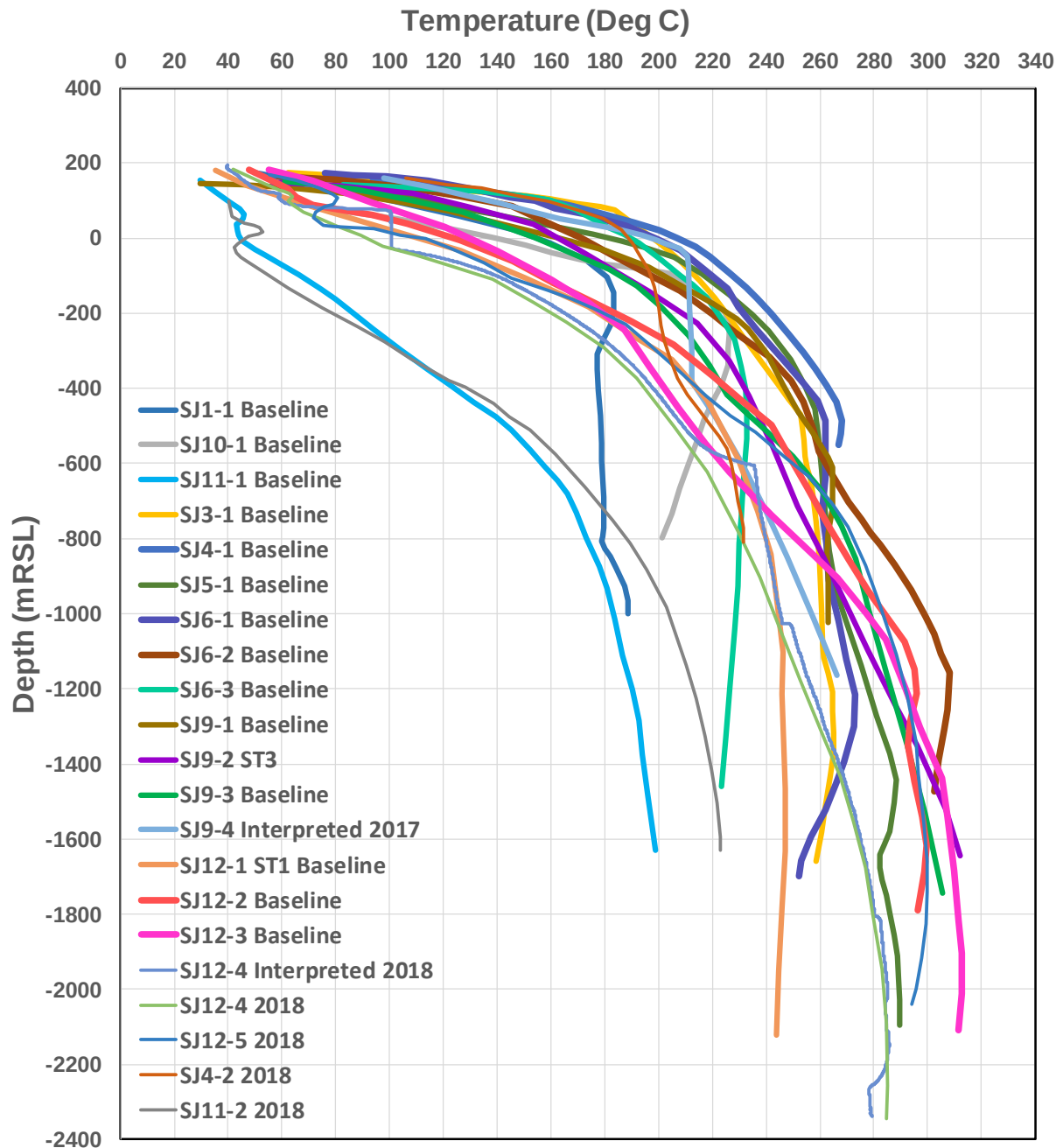


Figure 3: San Jacinto wells baseline and interpreted temperature profiles.

2.2 Reservoir Changes Over Time

Under production, the pressure and temperature conditions in the reservoir change from the initial natural state conditions. This can also lead to changes in the presence and extent of any 2-phase or “steam zones” where steam becomes the main mobile water phase rather than liquid water. Interpretation of these reservoir changes across the system relies largely on interpretation of PT logs in wells, much the same as we interpret the natural

state conditions. As pressures change however, and as wells are used for production, it becomes increasingly complex to interpret reservoir conditions from periodic PT logs. This process and the observed changes are also reported fully in Section 5.1 of the Concept Model Update report (Jacobs, 2019).

Only well SJ3-1 was able to be continuously monitored for pressure change over a long period, but although this well appears to be connected closely with the western side of the system, it appears to not be strongly affected by the main production further east and so does not give good insight to broader reservoir pressure change.

Therefore, most reliance for assessing pressure change in the system has come from the semi-annual PT logs in production and injection wells when they are briefly (usually 1 week) shut in during major plant maintenance that is conducted annually, alternately on Units 3 and 4 (see Figure 4). This data has uncertainty regarding whether the pressures are stabilised to represent reservoir conditions or still “recovering”, and how the overall plant shut down may affect pressures in a dynamic sense compared to normal operation. But this data is reasonably consistent and useful as a guide to understanding reservoir behaviour.

In addition, most wells have more than one feed zone at different elevations, but the conditions at separate zones cannot be measured separately and are influenced by the wellbore which allows the major feed zone to dominate well conditions when the well is shut. This means we cannot measure pressure changes in secondary zones, or that observed pressures are reflecting a combined at several levels in the reservoir. For this reason, we show the interpreted pressure trends at the main feed level and compare with the calculated pressure trends at all feed zones in production and injection wells as determined in the model. We don't expect an exact match to pressures at the main feed, rather a consistency with how the pressures at several levels on the model may result in the observed trends seen in wells.

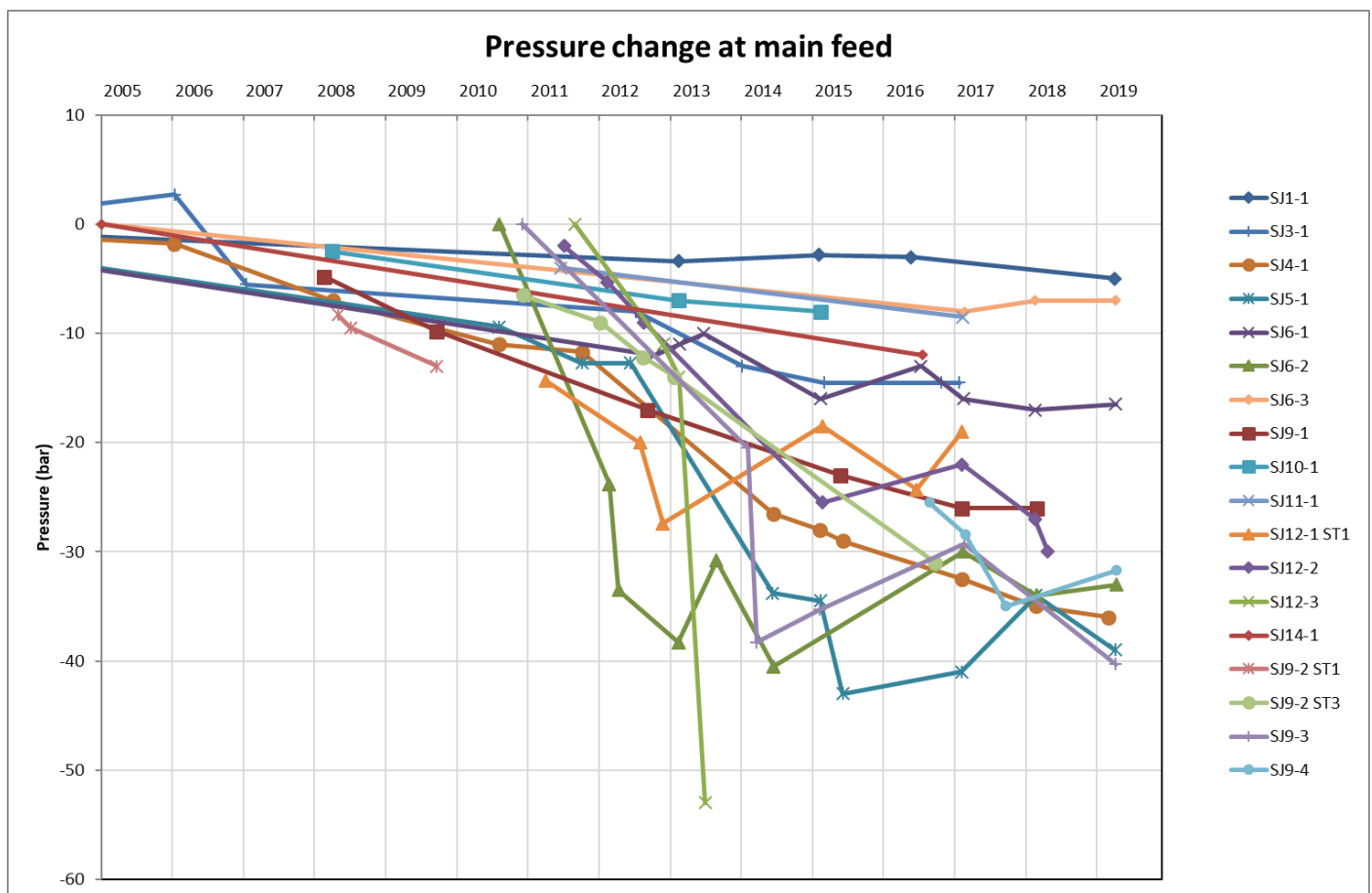


Figure 4: Pressure trends observed in all wells.

The monitoring data indicate a distinct difference between two spatially distinct groups of wells, namely:

- **Central to western wells** (SJ3-1, SJ4-1, SJ4-2, SJ6-1, SJ9-1, SJ9-4, SJ12-1 and SJ12-2): Many of the first group of wells showed an initial gradual decline ($\Delta P < 10$ bars) in downhole pressures following commissioning of the 10 MWe back pressure plant in 2005. This was followed by a sharper and larger decline ($\Delta P \sim 30$ bars) in response to the increased mass extraction following the commissioning of the 72 MWe plant in 2012. Overall, the pressure drawdown effects are less towards the west and the variations are possibly due to the effects of reservoir compartmentalisation as indicated by large pressures gradient between some wells (e.g. SJ3-1 and SJ5-1). Furthermore, marginal fluids may also be providing better pressure support in the west. This is supported by the changing chemistry of SJ4-1, SJ6-2 and SJ9-1.
- **Eastern wells** (SJ5-1, SJ6-2, SJ9-3, SJ12-3, SJ12-4 and SJ12-5): This group of wells mostly produce from deep feed zones in the eastern part of the field have also experienced substantial pressure drawdown ($\Delta P \sim 40$ bars) and which has occurred at a faster rate than seen in the western wells. This has most likely been influenced by the generally deeper and less well-connected permeability that appears to be more prevalent on the eastern side of the field. It is also possibly due to that side of the resource receiving less pressure support, which is possibly related to the thick low resistivity (low permeability) unit that is present there.

In general, the pressures have seen a significant decrease with the early years of the project, particularly when units 3 and 4 came on line in 2012-13, but generally appear to be stabilised, which is reflected in the somewhat stable production rates of wells as shown in the next section. SJ4-1 and SJ9-1 have seen more steady declining pressure, and the SJ9-4 feed which was interpreted to be already drawn down when drilled in 2016, has seen a step decline of about 10 bars since being on production. We do not have calibrated data for decline of pressure in SJ12-4 and SJ12-5 since they were on production, but we do have an indication of the drawdown in that area to 2017 from assuming natural state conditions consistent with the adjacent wells, and comparing that with static pressures found when the wells were stabilised after drilling.

In general, the field is not presently seeing steep pressure decline, and when the numerical model is calibrated to this trend, it will naturally indicate that there is modest flow decline.

However, we are seeing that several wells have become more sensitive to declining pressure or localised drawdown on specific feed zones and there is increased cycling, operating at low flow modes for extended periods, or failing for periods to deliver at enough pressure to feed into the production system. SJ12-4 (which has low permeability) and SJ9-3 (which as fork legs and other zones that interfere) are increasingly off line and SJ6-2 increasingly operates in a low flow mode (when its deeper feed declines and stops producing). These have a significant impact on total steam produced per month, and when the effects happen concurrently, can have a marked impact on the net power produced from the plant. The reservoir modelling will not (at this stage) attempt to model these transient effects in well behaviour, but should be able to offer some useful insights into reservoir behaviour that lies behind some of these effects – particularly how pressures are changing at different levels and affecting the various feed levels in these wells.

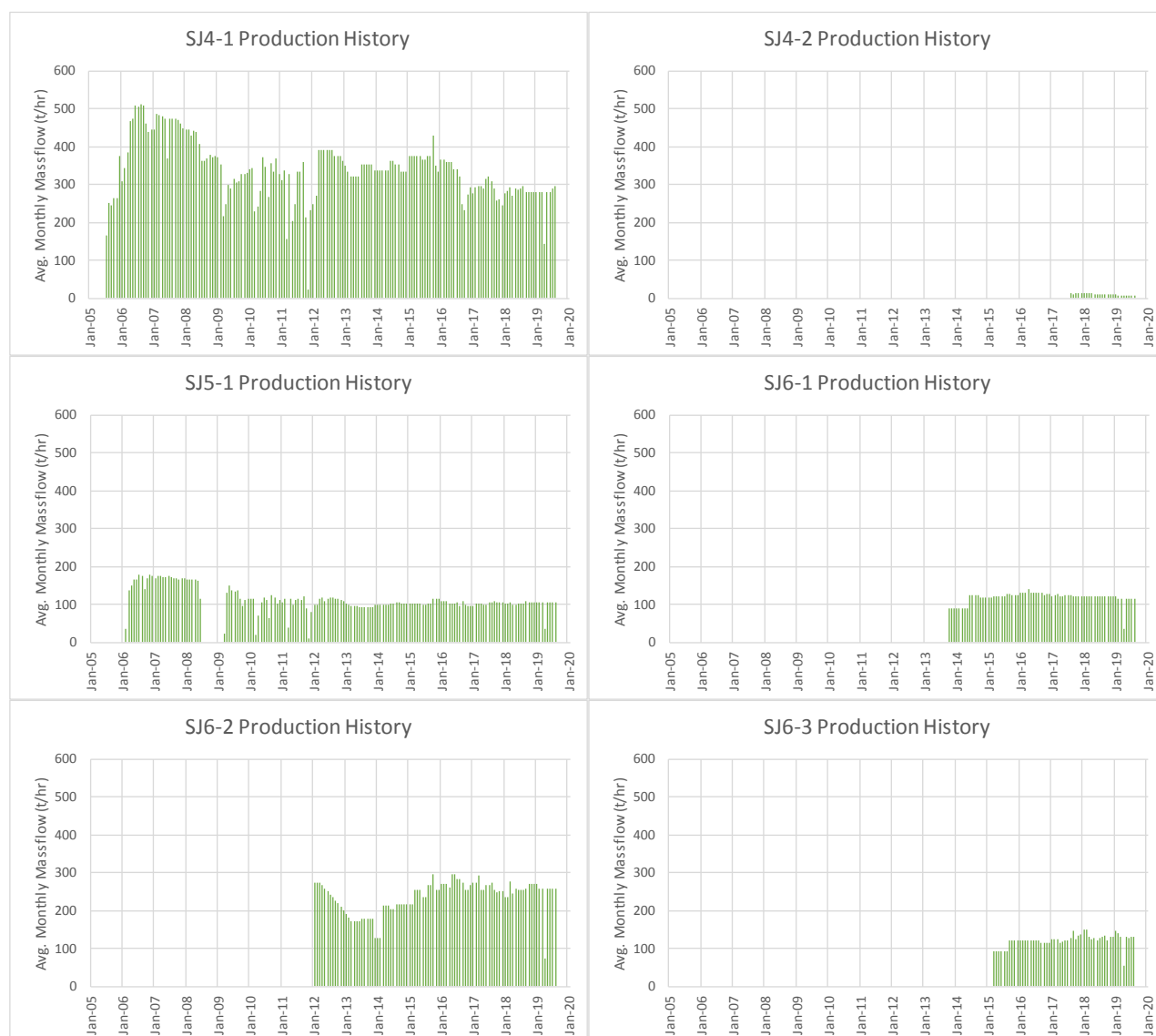
3. Production and Injection Data

Historic production data are a key input to the numerical model, as this drives the mass changes in the system that create pressure change that is an important calibration of the model. Matching historic pressure and enthalpy trends is probably more important than matching the natural state temperatures. These history trends will be affected by ongoing project production, and any changes in reservoir management – our main interest in doing this modelling.

Mass flows are a given for the modelling, whereas the observed enthalpies are data to which the model attempts to match – a calibration.

3.1 Well Production Data Update (2005-2018)

The monthly averaged production history per production well is shown Figure 5. The majority of production wells (SJ5-1, SJ6-2, SJ6-2, SJ6-3, SJ9-1 and SJ12-2) have maintained moderately stable production from 2015 to 2018. Production wells SJ9-3, SJ12-3 and SJ12-4 showed variation in production mainly driven by well cycling behaviour.



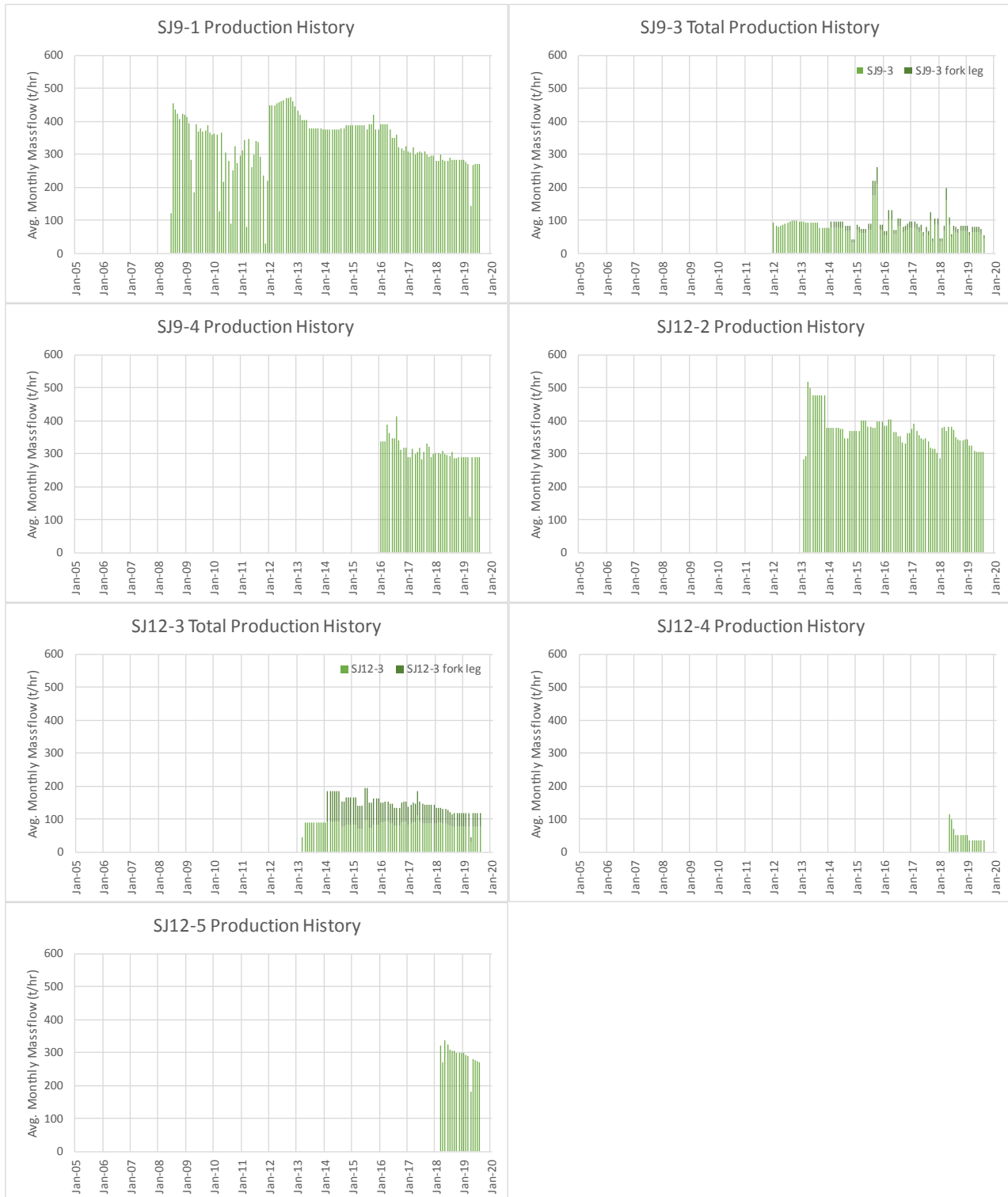
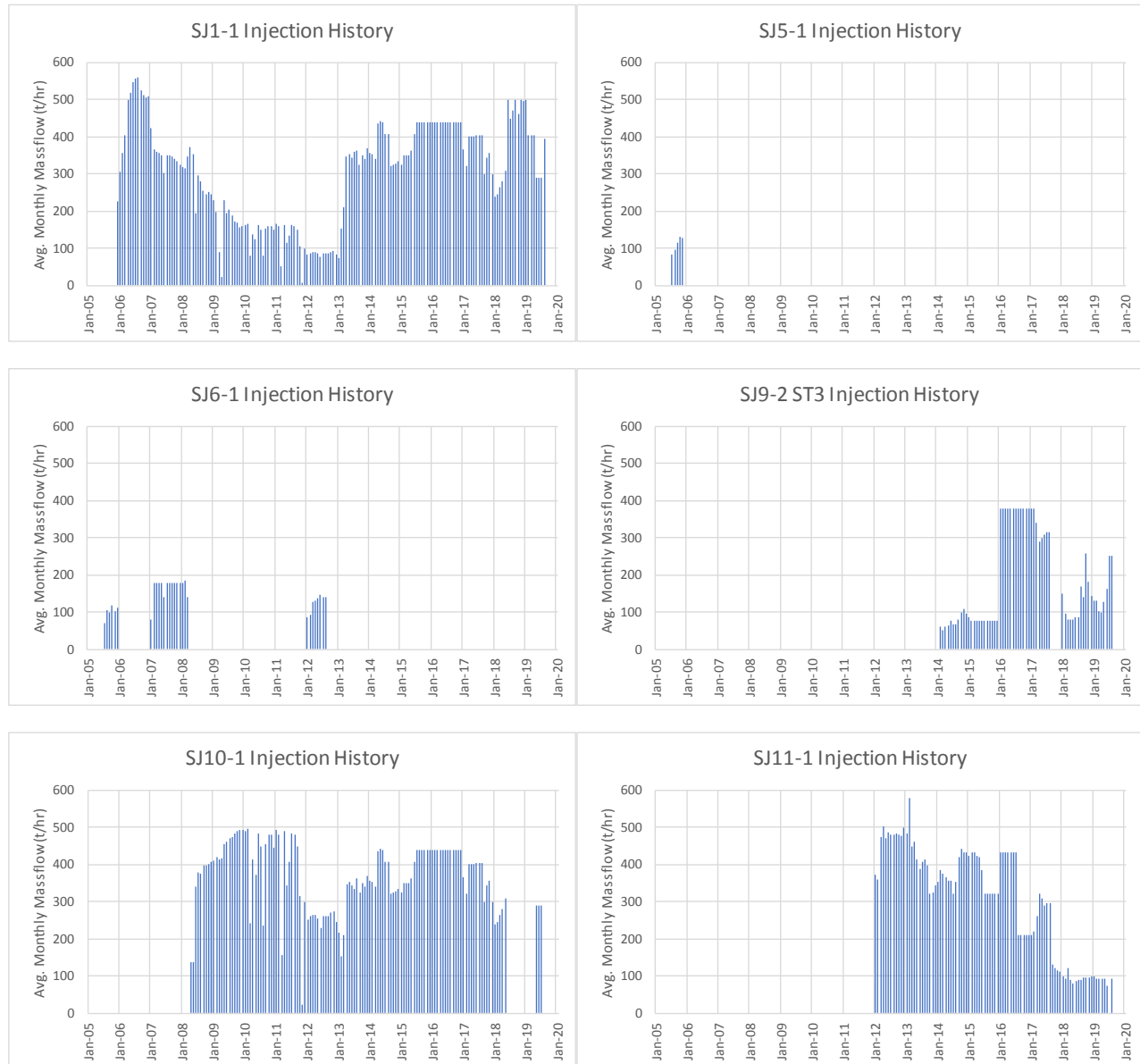


Figure 5: Monthly averaged mass flow for each production well. Note that forked wells have had fluid allocated to the original and fork leg for input to the numerical model.

3.2 Well Injection Data

There have been many changes in the location of injection at San Jacinto, and this complicates the calibration against pressure trends over time because many changes of fluid production and injection are happening simultaneously, and only a few strong correlations of production / injection have so far been identified.

Initially injection for the commercial demonstration plant, injection was in wells SJ6-1 and SJ5-1 but in late 2005 injection was moved to SJ1-1.



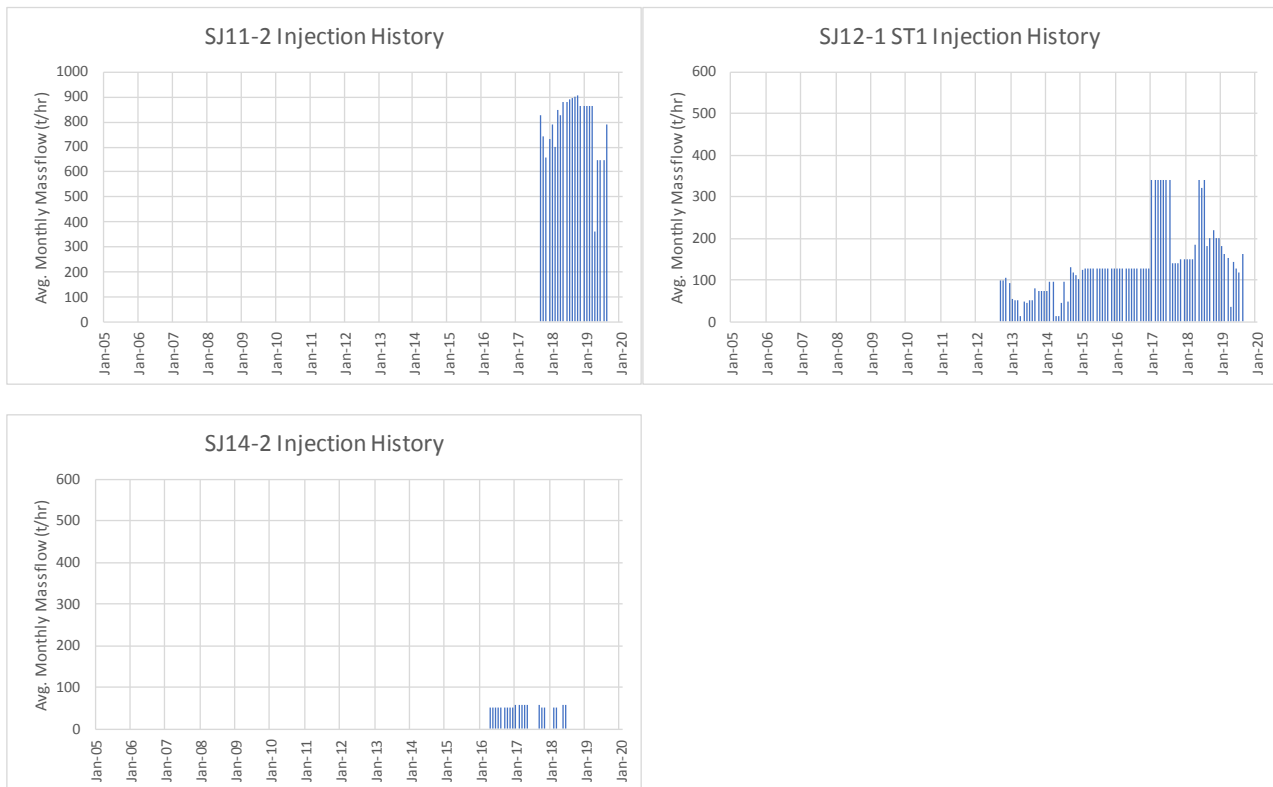


Figure 6: Monthly averaged mass flow for each injection well. Note that SJ5-1 and SJ6-1 have also served as production wells.

3.3 Tracer Testing

Tracer tests for tracking injection fluid movement in the reservoir were reported in the recent concept model update for surveys made in 2015-16 and 2018-19. Data for the 2018 sampling is still being collected and is not yet modelled, but indicative travel times and quantities have been reported.

The strongest and most notable injection returns have been

- from **SJ10-1** to SJ4-1, SJ9-1 and SJ6-2;
- from **SJ12-1** to SJ9-4 and SJ6-1 (more in 2015 than in 2018); and
- from **SJ9-2** to SJ6-2.

The fastest returns were from SJ12-1 where wells nearby (SJ5-1, SJ12-2 and SJ9-4) saw tracer returns in 3-4 days. In this case, the strongest return by volume was to SJ9-4 where the two wells have deep feeds that are quite close. The upper parts of SJ12-1 and SJ12-2 are very close (being from the same pad) but the results only indicate minor amounts of injectate return.

Which zones may be acting as the tracer flow paths is often unknown, particularly for some close wells such as SJ12-1/12-2, so it can be challenging to model the tracer flows explicitly. The flow rates seem to also vary over time as reservoir pressures change. SJ12-1 had a stronger connection to SJ6-2 in 2015-16 than in 2018-19, probably because there is now more drawdown in the central reservoir / and or injection from SJ11-2 is now deflecting such flows. For the present model (and while the 2018-19 data is still being processed) the tracer flows have been used as a guide to the modelling and tracers have not yet been explicitly matched. This would be the subject of further model refinement, and probably using double porosity approaches.

The results of the two main phases of tracer testing is summarised in the following graphic, which shows 2019 production and injection flows as a “bubble plot” with diameter proportional to well production or injection, and arrows showing observed tracer returns (actual flow direction is unknown – this is a schematic diagram only).

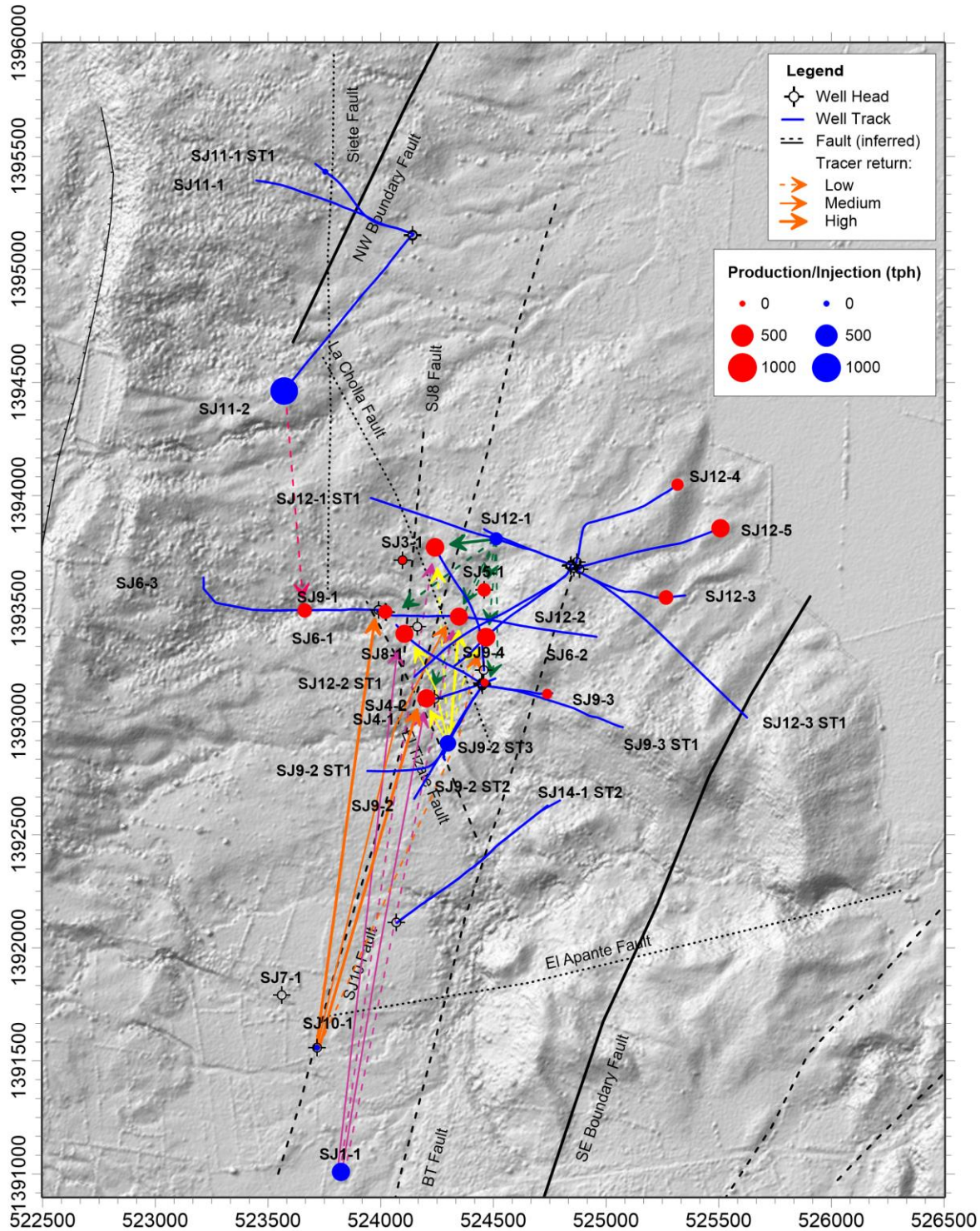
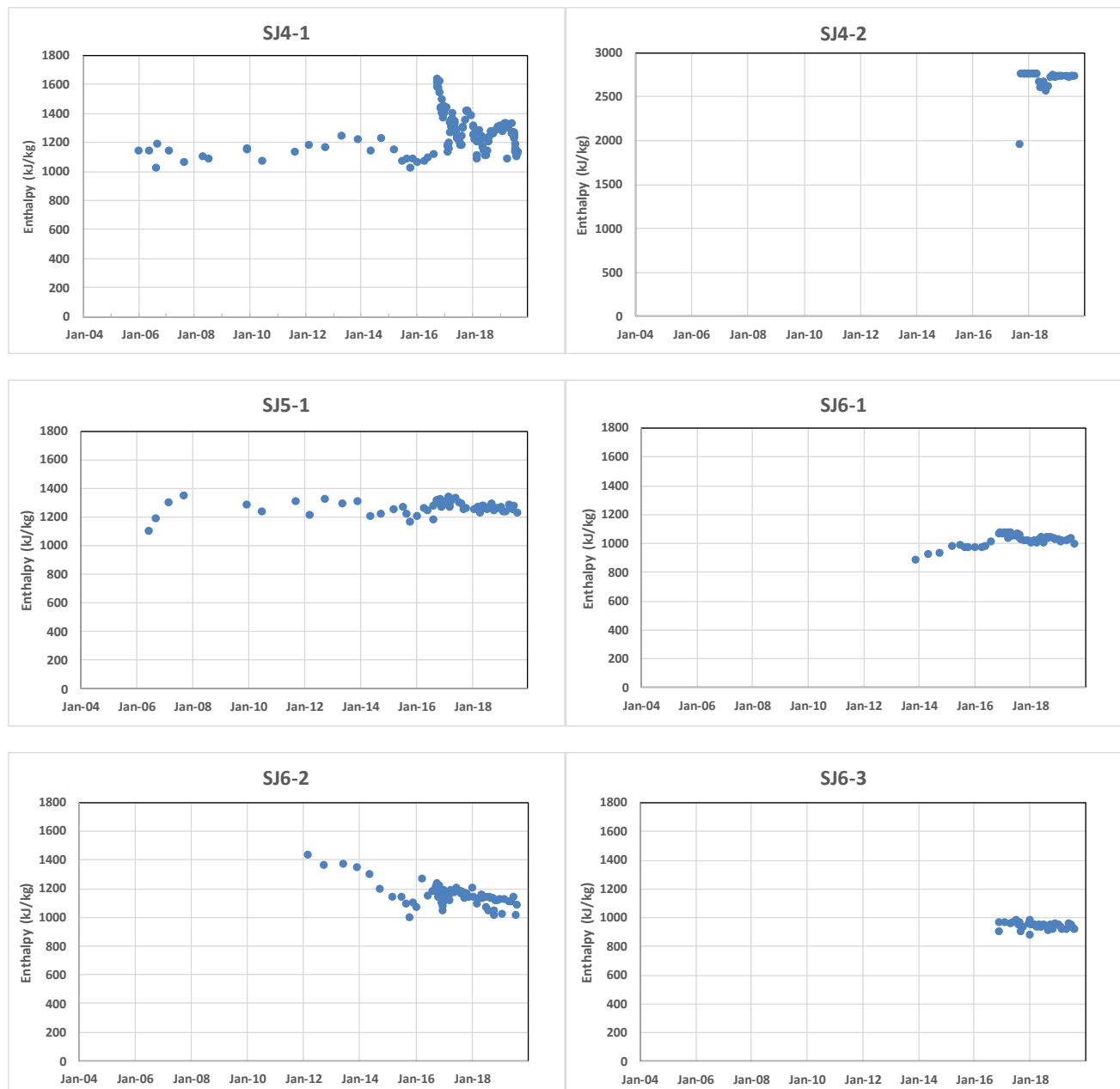


Figure 3.7: Map showing production and injection (2019) with a schematic summary of observed tracer returns (arrows indicate well to well connection). Dashed arrows are minor returns (<5%), solid lines are modest returns (5-12%), and thick arrows are significant returns (>12%)

3.4 Enthalpy Trends

The corresponding well enthalpies with time are provided in Figure 8. The majority of wells have maintained reasonably stable discharge enthalpies within the 1,000 – 1,400 kJ/kg range, with the main exceptions being:

- SJ4-1 showed a steep enthalpy rise in 2015 and is thought due to the progressive expansion of the steam zone. SJ4-2 has the highest production enthalpy (~2,740 kJ/kg) in the field as it has a relatively shallow completion depth and produces only from the steam zone.
- SJ6-2 showed an initial declining enthalpy trend since being placed in to service in 2012, but then reached a moderately stable production enthalpy of ~1,150 kJ/kg after about 2 years of operation.
- SJ9-3 and, to a lesser extent, SJ12-3 have shown a trend of enthalpy variation that is caused by well cycling behaviour. This appears to be due to the more irregular permeability distribution on the eastern side of the resource and is likely to be exacerbated by the multi-lateral (forked) completion of those particular wells.



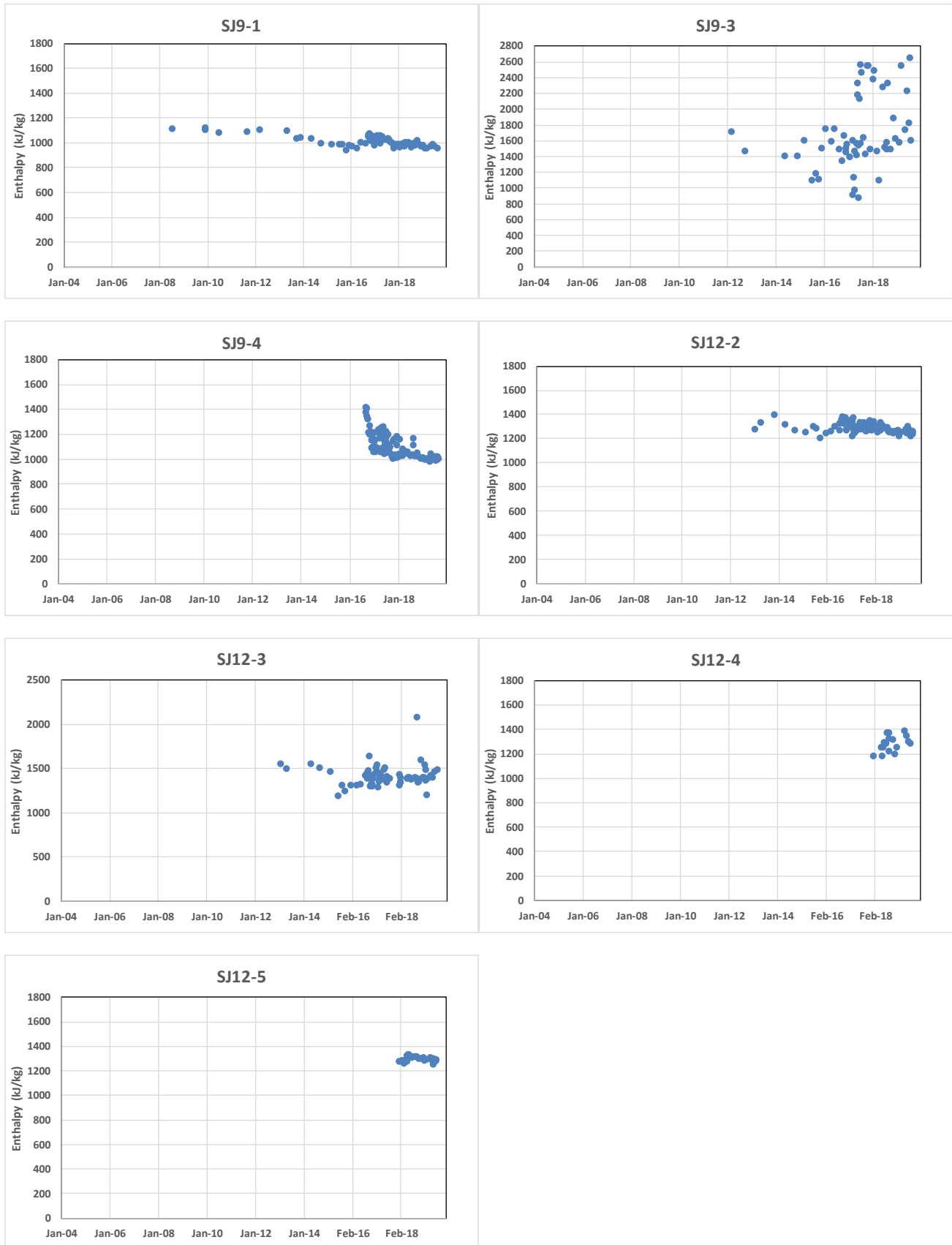


Figure 8: Production well enthalpies over time

4. Key Elements Being Modelled

Substantial effort has been placed in developing the numerical model framework to closely reflect the key elements of the updated conceptual model for the San Jacinto resource. A summary of these elements and how they have been incorporated into the numerical model is given in the following Table 1.

Table 1: Incorporation of concept model elements into numerical reservoir model

Concept Model Element	How This is Included in the Numerical Model
Resource area and volume	- The clay alteration “cap” mapped from MT is used to define likely system boundaries and overall model extent. Also used to define likely system outflow paths. The clay cap may not define present system limits, and the high resistivity areas under the cap may not be all permeable, but this is a starting point for possible extents, which have then been refined (usually brought inwards) to achieve a match with observed pressure changes. - The Model has been extended to include San Jacinto west sector based on conceptual understanding and interpreted proximity to San Jacinto-Tizate. No direct hydrologic connection between sectors, but an upflow was required in this area to minimise the temperature inversions that otherwise appeared in the west of San Jacinto without there being hotter fluids to the west.
System heat source	No specific heat source is defined, but there must be a localised upflow of hot fluid in the central / east area.
Reservoir geology	Limited variation of volcano-stratigraphic lithology is seen across San Jacinto apart from SJ7-1 and SJ10-1 seeing dioritic bodies. A basic layered stratification has been used as a ‘background’ lithology with generally decreasing permeability with increasing depth.
Permeability controls	- Rationalisation of previously mapped discrete faults with only those with high degree of confidence (e.g. SJ10 Fault) included in the model. - Model structure uses strong NNW-NNE striking anisotropy with broadly distributed permeability in this direction and which is mostly steeply dipping (>80°) in accordance with subsurface data (e.g. FMI logging). - Permeability in NNW-NNE striking direction set substantially higher than in the E-W striking direction.
System hydrology	- The area appears to have a relatively open hydrology with water levels near surface apparently affected by reservoir pressure drawdown, so an air-water model surface has been used that allows shallow ground water levels to vary in response to deeper changes. It also allows for the open drainage from the high ground to the west of San Jacinto-Tizate. - It was challenging to get the upflow in the east of San Jacinto to flow westwards against the naturally higher hydrological levels in the west, but this was assisted by allowing outflows to the south and some pressure sinks

Concept Model Element	How This is Included in the Numerical Model
	to the southeast. These outflows are necessary to get the spread of temperature south to the SJ1-1 injection area.
Outflow to south	- A significant outflow to the south seen in SJ10-1 and SJ1-1 (temperatures about 200°C, temperature inversion, and the pressure response [decrease] in response to production) has been included through a combination of the N-S structural permeability, inclusion of some shallower stratigraphic permeability and allowing mass output at the Los Hervidores thermal area. This southerly flow was facilitated by also allowing some outflow to lower elevation along an eastwards path from San Jacinto village area. - Present modelling shows cooler conditions at depth in the south (beneath SJ1-1 and SJ10-1) than in the concept modelling, but there is no actual data to better control which is correct. Greater heat input at depth in the south could better improve the match to concept model.
Steam zone development	- The localised vertical permeability from the main N-S permeable zones has allowed the development of the observed high temperatures at shallow levels within the central part of the system. - The air water model has allowed pressure drawdown deeper in the system to allow development of 2-phase conditions with steam becoming the mobile phase in the upper system.
Lower temperature and inversion in west	- Achieving the observed temperature inversions in SJ3-1, SJ6-1 and SJ6-3 in the west has required addition of some horizontal permeability so hot fluid can flow west from the upflow. But this needs to be balanced with observed modest pressure change in the west compared with substantial pressure drawdown in the central / east part of the system. - When permeability was relaxed to allow outflows, it also creates strong cool inversions coming into San Jacinto at depth from the west. So, it was important to include the postulated geothermal system in the western sector to minimise this cooling. That western system could even be stronger than yet modelled to improve the natural state matching.

5. Reservoir Model Design

This section presents and discusses the design of the updated model. The most important points can be summarised as follows:

- The grid has been extended all the way to surface of the system and the shallow layers refined enabling the interaction of the evolving shallow steam zone and the water table to be accurately represented.
- A framework that is consistent with the conceptual model has been developed for representing the subsurface in the model.
- The framework takes into account the lithology, alteration and structural settings in different zones of the system.
- The framework facilitated the assignment of the initial rock properties but also helps ensure that the model remains consistent with conceptual model during calibration.

5.1 Model Grid

As for previous models of San Jacinto, the AUTOUGH2 reservoir simulation platform was again used for this major rebuild of the San Jacinto numerical reservoir model. An air-water model was used, with the top surface of the model following the topography. This removes the need for assumptions about the water table and allows an accurate representation of shallow boiling. The model covers around 340 km² and extends from the surface to an elevation of -3,200 masl. The highest resolution model blocks cover the productive part of the system and are 125 m x 125 m. The total number of blocks in the model is approximately 40,000.

The results of the expanded MT geophysical survey completed in 2017 helped define the interpreted outer boundary of the productive resource, especially in the northern part of the field. The survey results also improved the resolution of the prospective geothermal resource on the northern flanks of Telica volcanic complex, referred to as the Western Sector which had to be included to help match temperatures on the west of San Jacinto.

The plan view of the updated model grid is presented in Figure 9. The layer structure of the new model grid is also presented in Figure 10.

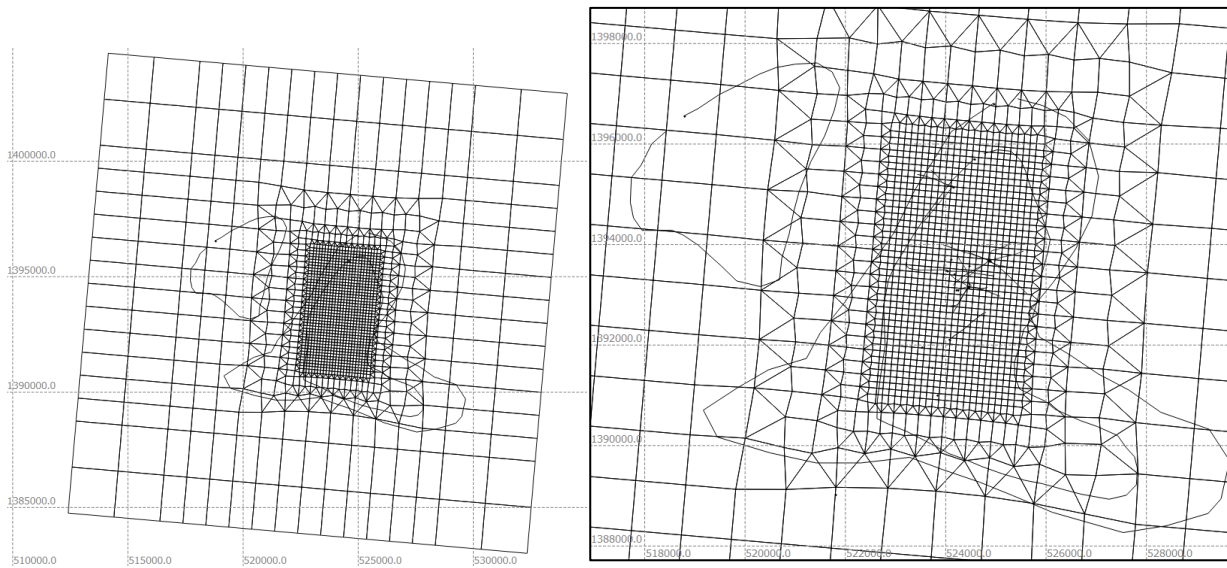


Figure 9: Plan view of the layout of the San Jacinto numerical model. This shows that the grid rotated slightly away from the north-south axis. This aligns the model grid with the dominant structural trends and allows the anisotropic permeability distribution they cause to be represented more effectively in the model. Left is the whole model, and right is the central area.

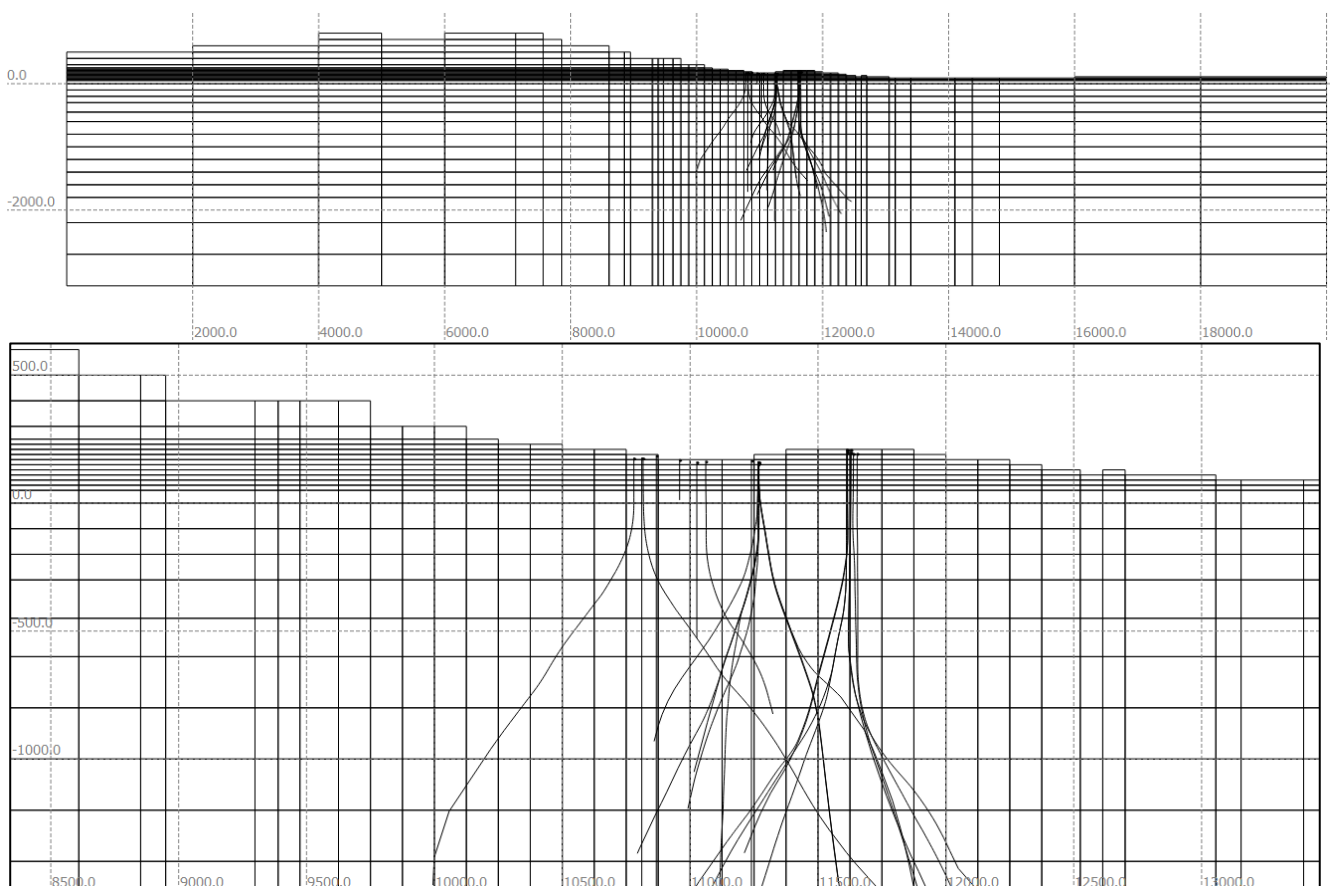


Figure 10: Model grid sections. This shows that a highly refined vertical grid is used from 250 masl to 50 masl covering the top 200m of the productive system. This allows for an accurate representation of the water table, the vadose zone and their interaction with shallow boiling.

5.2 Rock Type Distribution

As discussed in Section 4 the new model attempts to represent current conceptual understanding of the system as closely as possible. One important aspect of this approach is using the conceptual model is to assign the distribution of model “rock types”. Model rock types is an unfortunate historic TOUGH2 term. Model rock types are actually groups of model blocks with the same rock properties (i.e. permeability, porosity, density etc). In some cases, one real lithological unit must be divided into several different model rock types to allow different parts of the unit have different properties. Also, in other cases, it is convenient to group different real lithological units that have similar rock properties into a single model rock type. For the purposes of this report, the term rock type will be used to indicate a group of model blocks with the same rock properties.

The factors contributing to a model block’s rock properties are:

1. Lithology
2. Alteration
3. Structural setting

The lithology of the system is not clearly defined at present. As a result, the model lithology was assumed to be layered volcanic units as is typically found in geological settings such as San Jacinto. An east-west slice through the SJ12 pad showing the model lithology is presented in Figure 11. Five basic lithologies were assumed: basement, lower volcanics, mid volcanics, upper volcanics and superficial formations.

These five basic lithologies are assumed to be zones where the following conditions are found through local variation from these assumptions as a result of calibration is expected:

Basic Lithology	Typical Permeability	Description
Superficial formations	Very high horizontal, medium vertical	A wide range of formations including surface soils and geologically recent alluvium. Must be very high horizontally to allow shallow groundwater flow and the water table to settle at the correct level.
Upper volcanics	Medium horizontal, Low vertical	Recent lava flows and deposits. Often young lava flows have low permeability but deposits between lava flows and the rock along the lava flow margins can be quite permeable. The layering and grouping of these different types of geology result in typical permeability.
Mid volcanics	High horizontal, Medium to Low vertical	The same as for upper volcanics though over time lava flow may be more fractured by local stresses creating better permeability.
Lower volcanics	Fair	As the pressures and overburden increase pathways in older volcanic formations become more compressed leading to lower permeabilities.
Basement	Low	Older formations, possibly intrusive or sedimentary. Low permeability apart from fracturing which tends to be associated with structural setting.

The expanded MT geophysical survey has been used to create a simplified representation of alteration in the model. Zones with resistivities of 12 ohm-m or less have been assigned as potentially altered whereas those with resistivities above 12 ohm-m are assigned as unaltered. Figure 12 shows 2D and 3D views of the MT model overlaid on the model lithology and the resulting assignment of potentially altered zones.

Finally, north-south structural trends were applied to the model. In line with the conceptual model, this trend was assumed to dip towards the east with depth in the productive part of the system. Plot (a) in Figure 13 shows the

model blocks affected by the structural setting on the same E-W slice through pad 12. Plot (b) is a plan view at -525 masl showing how the north-south structural trends are included in the model. Note that not all of the structural trends have the same alignment with some trends crossing others. This allows them to act as barriers to the north-south flow direction as discussed in the model calibration section (Section 6). Also, note that to ensure that the sub-surface flow honours the structural trends despite the use of a rectangular model grid in the production zone, the face permeability directions are modified (see O'Sullivan *et al*, 2019).

While the representation of each of the three contributing factors is quite simple, their combination leads to many model rock types with a heterogeneous distribution. This rock type distribution honours the conceptual model while allowing a high degree of flexibility. Once the rock type distribution had been assigned, the rock properties themselves are determined through the calibration process that also honours geological principles as discussed in Section 6. The final rock properties distribution in model layer 26 corresponding to -525 masl is shown in Figure 14. Note that having a heterogeneous rock type distribution does not require that the rock properties are also very heterogeneous. In many cases, once the model was calibrated it was found that neighbouring rock types have similar rock properties.

The general lithology layering was represented with four layers through the model as shown in Figure 11. In general, the permeability decreases with deeper layers. Within these 'background' layers additional detail was imposed as necessary to constitute the reservoir permeability and bounding impermeability.

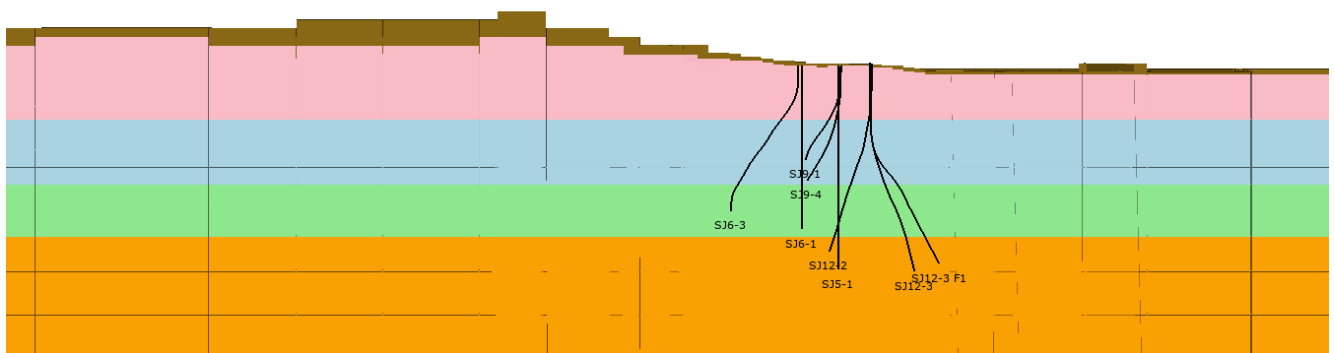


Figure 11: Model representation of the systems lithology. Basement (orange), lower volcanics (green), mid volcanics (blue), upper volcanics (pink) and superficial formations (brown). Basement is assigned a low permeability, lower volcanics fair permeability, mid volcanics good permeability, upper volcanics low permeability, superficial formations very high horizontal permeability.

The hydrothermal alteration identified as low electrical resistivity zones by the MT resistivity modelling is used as a guide to mapping possible top and bounding lower permeability (Figure 12). This interpreted 'clay cap' was given lower permeability generally, and the area enclosed beneath the clay cap a generally higher permeability as a starting point for controls on permeability outside the drilled area. However, these assumptions are allowed to be modified by the calibration process (see Section 6) as additional constraints are identified such as thermal fluids migrating upwards through the clay cap or where areas 'inside' the system area defined by the clay cap, proved necessary to be assigned lower permeability.

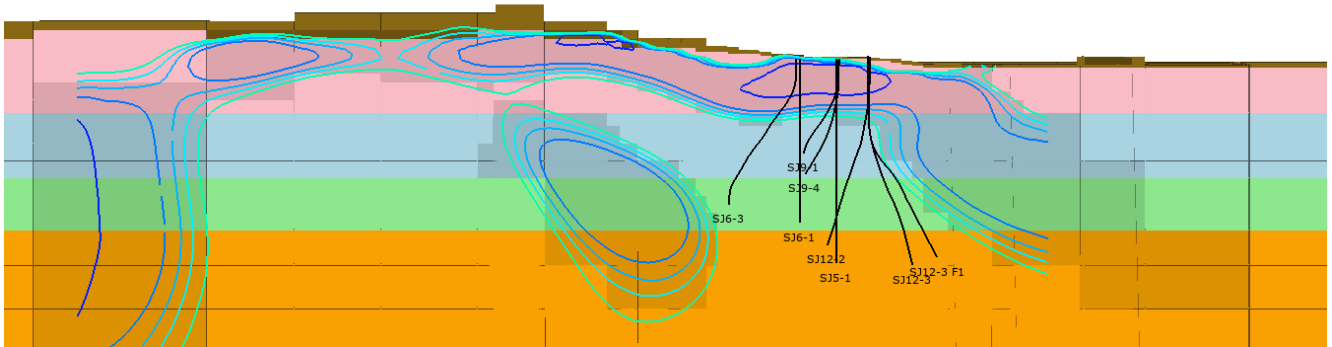


Figure 12: Model representation of hydrothermal alteration. Contours of MT survey up to 12 ohm-m shown with model corresponding model blocks shaded. These blocks were assumed to have generally very low permeability as a result of alteration. Local variation from this assumption was determined through the calibration process.

The presence of semi-vertical fracture permeability has been represented by several fault-zone type structures in the model that are vertical or dip steeply to the east in the eastern side of the system. These are intended to generally represent the near N-S main permeability that has been interpreted in the system that allow deep upflow in the system plus some of the N-S flow of fluids, and also create the apparent barriers to pressure transmission between the west and east sides of the reservoir (Figure 13).

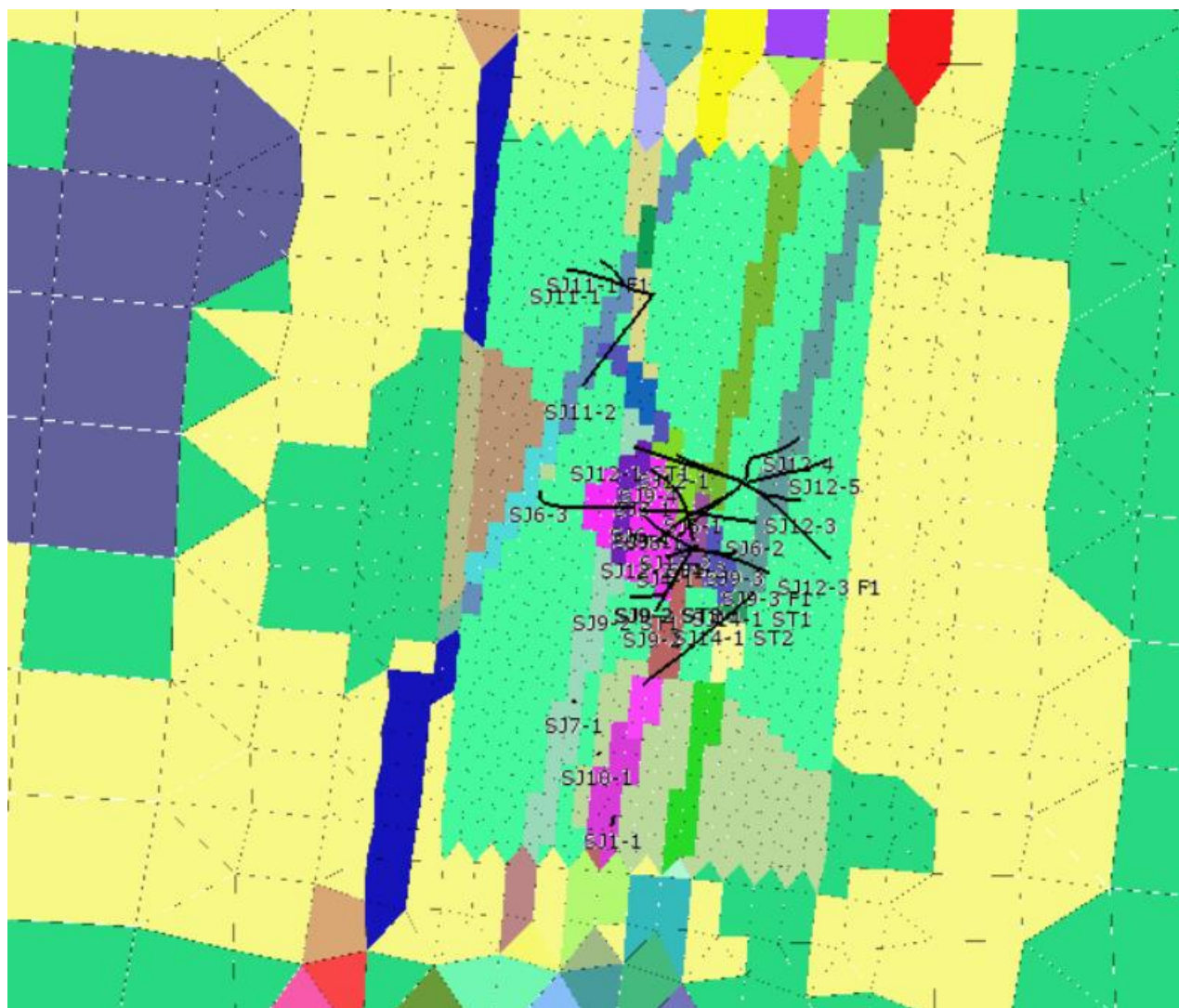


Figure 14: Model rock type distribution in model layer 26 at -525 masl.

5.3 Boundary Conditions

The reservoir model boundaries were set-up using current best practices as follows:

- **Reservoir side boundaries:** Closed. The fixed (zero flow) reservoir model edge boundary conditions are considered acceptable since the model grid extends far enough (> 7 km) away from the productive area.
- **Top reservoir boundary:** Open to single atmospheric block. The reservoir top boundary was fixed at air atmospheric conditions to ensure air could flow into the top reservoir blocks and water or air could flow out of them. Rainfall was also applied over the surface of the entire model corresponding to an annual rainfall of 1,520 mm with an infiltration rate of 10%. Both the air atmosphere and the rainfall were set to 22°C.
- **Bottom reservoir boundary:** Closed, with heat and mass input. The 2015 model presented a number of scattered areas of mass input covering a wider zone of the hot reservoir. The updated model has been improved by placing the mass input at the bottom layer in blocks corresponding to the zone identified as the deep upflow by the expanded MT geophysical survey. The dipping structural trends

were also used to constrain the locations of the deep upflow mass inputs. The locations of the calibrated deep upflow inputs are discussed in Section 6. For the deep heat input a uniform distributed heat flow of 160 mW/m² was applied to the base of the entire model. This is reasonable in a region of volcanic activity.

5.4 Dual porosity model setup

PyTOUGH scripting tools have been created which automate the process of generating the production history model from the natural state model. The tools create both a single porosity production history model and a dual porosity production history model. The important additional parameters required for the dual porosity model are the:

- Fracture volume and matrix volumes
- Average fracture spacing
- Average number of fracture planes
- Matrix permeabilities for each rock type

Using the standard dual porosity approach, the fracture rock type permeabilities are the same as the single porosity permeabilities assigned in the natural state model.

During the model calibration described in following section, several dual porosity versions of the production history model were run. However, run times are quite long taking more than 6 hours compared to ~1 hour for the single porosity production history model. Thus to make rapid progress calibrating the production history model the single porosity approach was used. The dual porosity model for the current calibration was run but its matches to the observed field data were worse than the single porosity model as the four parameters listed above have not been calibrated.

Now that the model is reasonably well calibrated as described in Section 6, a more focused effort to calibrate the dual porosity model can be carried out. This process would be significantly sped up by using the new Waiwera geothermal reservoir simulator (see Section 8).

6. Model Calibration

This section describes how the values of permeability within the basic ‘rock type’ distributions described in Section 5, were varied to achieve matches with the natural state and observed production data. It presents representations of the actual permeabilities (in x, y and z directions) and porosities in the reservoir and shows the quality of matches to the interpreted observed data.

The numerical model was calibrated based on the interpretive work performed by Jacobs using the PENSA baseline and production data from 2005 to 2019 that has been presented in Sections 2 and 3.

The main observations are as follows:

- The model has achieved a reasonably good match to the observed natural state temperature distribution in the reservoir, simulating the central upflow and outflow to the south. Calibration of the natural state has required the N-S structural grain or permeability interpreted in the concept model, but also required some barriers on the north side of the system to which are consistent with the apparent isolation of the SJ11 wells to the main reservoir.
- Some differences between observed and modelled data exist, but typically occur where the physical processes in the reservoir are semi-stable and temperatures can vary with small changes of permeability, presenting modelling challenges but which could be improved with future iteration of the model.
- The model has been further calibrated against observed pressure and enthalpy changes in the system with generally good matches to the system behaviour.
- The model has recreated the formation of the steam zone in the upper part of the system and shown variations of enthalpy that generally follow observed trends.
- Well productivity (the calculation method linking predicted reservoir changes with the effect on well production) for each well has been calibrated by varying the productivity indexes for each well feed zone to simulate the observed behaviour of wells since the beginning of 2018. These have shown good matches to observed behaviour, though because they have been referenced to varying plant operating conditions, may under-predict future trends slightly.
- There is opportunity for ongoing improvement, but this current model is considered sound for conducting predictive scenarios to understand the broad behaviours in the system and associated reservoir management options. Ongoing refinement will improve the ability for well-by-well behaviour modelling.

6.1 Natural State Calibration Results

The current natural state calibration achieved a good overall match to the wells’ stable interpreted temperatures. Individual comparisons between the model results and measured data are presented in Appendix A. The plots in Figure 15, Figure 16 and Figure 17 show the natural state model’s temperature distribution in detail and how well it compares with conceptual model. As discussed in Section 2, the conceptual model has been developed using all of the available field data and so achieving a good match with natural state model shows that it is a good representation of the system.

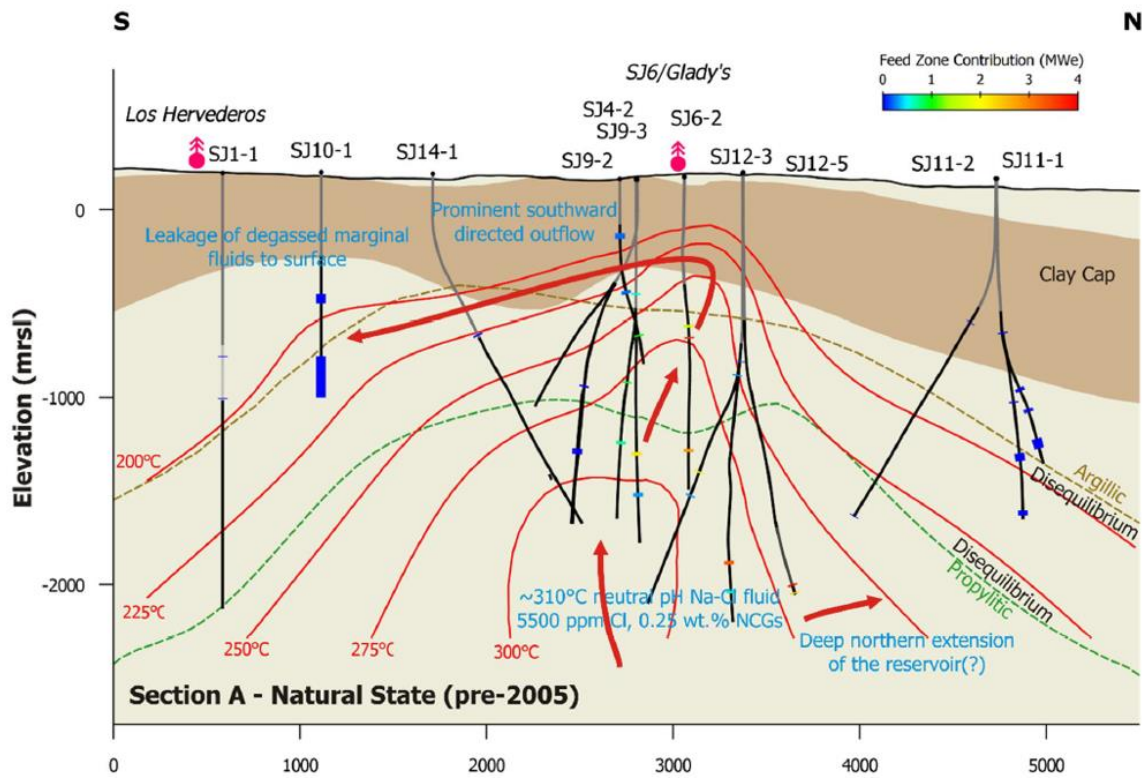
Several different important aspects of the temperature plume have been captured in the natural state model:

- The first can be seen in Figure 15 where the natural state model is matching the central upflow under the SJ4 and SJ6 pads before outflowing to the south to SJ1 and SJ10. The dominant north-south structural trend applied into the model was important for achieving this behaviour. Not only for creating high permeability preferential pathways from the centre of the system to the south but also for confining flows to the east and west with low permeabilities acting as barriers to flow in those directions. Details of the current calibration rock properties are given below in Section 6.3. Plot (a) in Figure 17 shows that the shallow outflow in the model continues south past SJ1 and is suspected to be the source of the degassed marginal fluid leaking to the surface at Los Hervidores. The upflow plume appears more

focussed in the numerical model than in the concept model but there is limited actual data to confirm which is more correct, and the numerical model may be highlighting that in reality there are cooler temperatures at depth in the south than in the present concept.

- Second, Figure 15a shows that temperatures decline quickly moving to the north from the centre of the system. Evidence from the production data (see Section 3) also shows that there are no injection returns from the SJ11 pad to the centre of the system. The change in temperature regime over a relative short distance combined with the lack of injection returns indicates that north-south structural trend must be interrupted just to the north of the centre of the system. Figure 15b shows that the model matches this behaviour reasonably well which was achieved by using the northwest-southeast structural trend shown in Figure 13 as a barrier to flow in the north-south direction. Note that the temperature distribution discrepancy between the plots in Figure 15 near the SJ11 pad is due to the SJ11 wells being out of the plane of the conceptual model cross-section in plot (a). In fact, the model temperatures for the SJ11 wells are currently too low rather than too high as is discussed below.
- Third, Figure 16a shows that the upflow moves from east to west as it rises and that it is relatively confined in the east-west direction (~ 1 km wide) in the production zone. It also shows that shallow temperatures in the SJ12 pad are lower than those in SJ3, 4, and 6 pads. Figure 16b and Figure 17 show that natural state model matches all of this important behaviour very well. This was achieved in the model by ensuring it was consistent with the conceptual model which suggests that the north-south structural trend dips to the east with depth and that the shallow conductor is deeper moving eastward from the centre of the system. Section 6.3 shows the upflow structures in the calibrated model have a dip to the east and that the altered rock identified by the MT required very low vertical permeability to prevent high temperatures rising to the surface at the SJ12 pad. Thus the natural state model calibration has helped to verify these conceptual model elements.
- Finally, Figure 16a also shows that temperatures on the western edge of the upflow (SJ6-3) are supported at depth in spite of the east-west confinement of the upflow. In calibrating the model it was found that including a reasonable representation of the Western Sector was important in achieving this. It can be seen in Figure 16b and in Appendix A that more calibration work is required in this area as a cool temperature inversion at elevations of -500 to -1,000 masl occurs in the model that is not present in the field data. At these elevations high permeability productive formations exist but there must be more low permeability in the western edge of the system than is currently in the model.

a)



b)

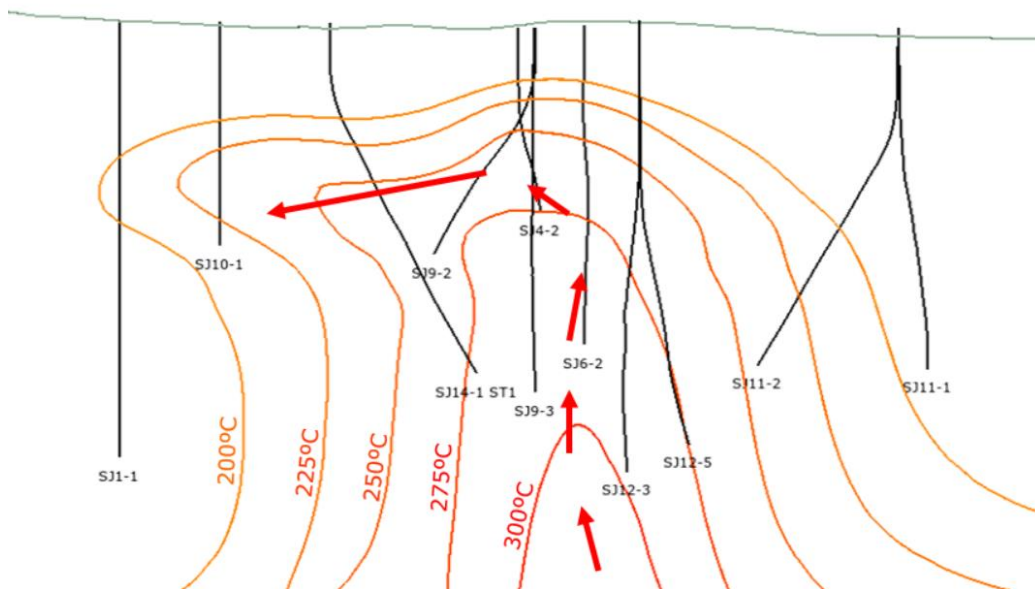
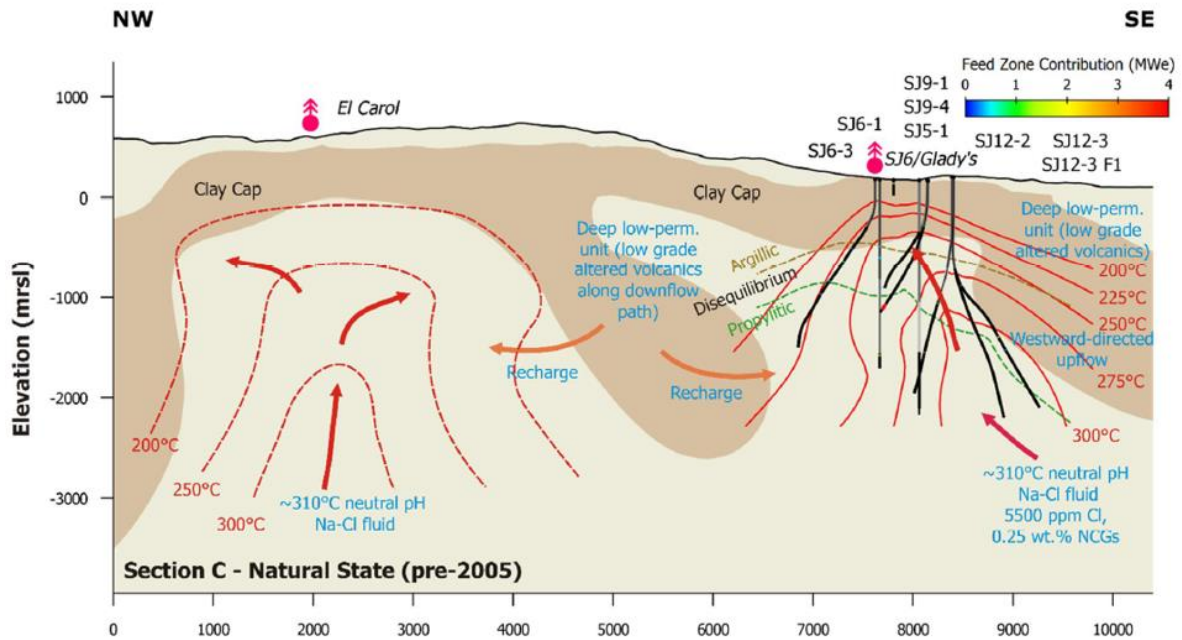


Figure 15: Comparison of (a) conceptual model S-N cross-section with (b) natural state model temperature distribution

a)



b)

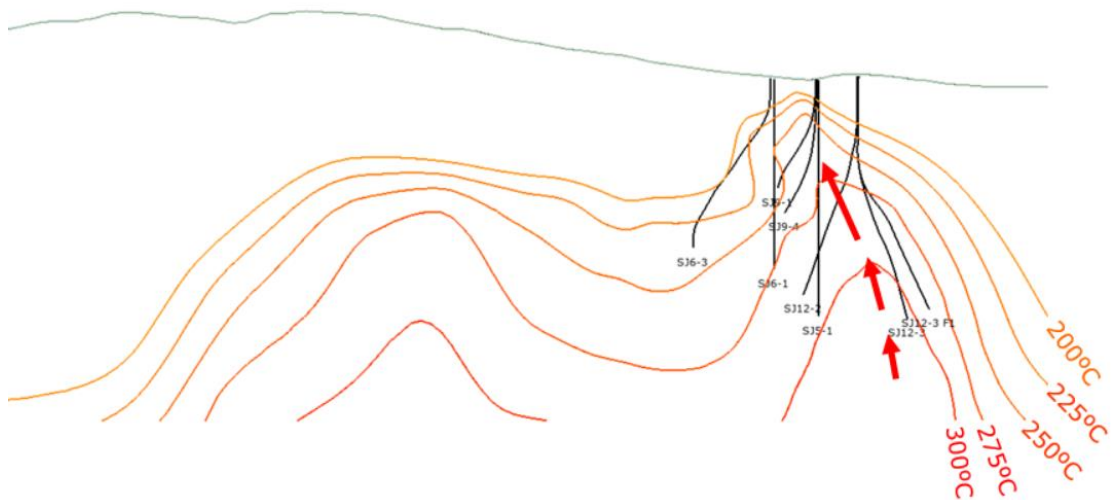


Figure 16: Comparison of (a) conceptual model E-W cross-section with (b) natural state model temperature distribution

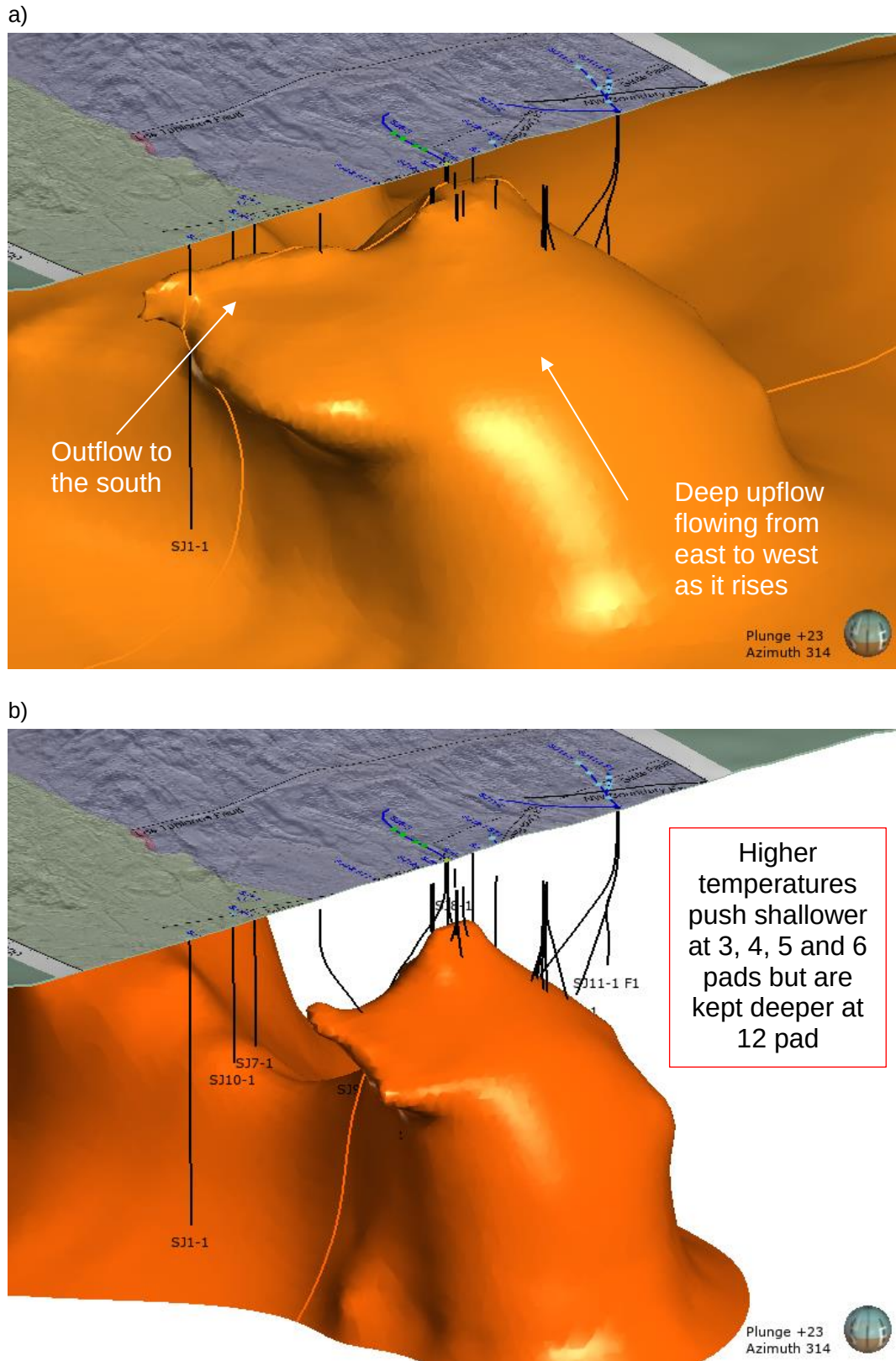


Figure 17: Modelled temperature plume in San Jacinto for (a) 200°C and (b) 250°C. Viewing angle is looking to the northwest

The following set of figures show comparisons of measured field data with natural state model results for different groups of downhole temperatures. The left hand plots show the locations of the wells, the central plot shows the measured field data and the right hand plot shows the natural state model results. The figures support the discussion above and also shows some areas where the model calibration can be further improved.

The plots in Figure 18 show that the model matches the suppressed shallow temperatures at the SJ12 pad as well as the variation in the bottom hole temperatures. Some improvement could be made increasing the deep temperatures in SJ12-3 and SJ12-5 though this is difficult to achieve and must be done carefully if the good match to the lower deep temperatures found in SJ12-4 and SJ12-1 are to be retained. As discussed above, some more calibration is required to confine the high permeability production zone between -500 and -1,000 masl. Figure 18 shows that currently at these elevations in the model the hot central system is still flowing to the north too much causing a slight outflow profile in SJ12-1 which is not present in the observed data.

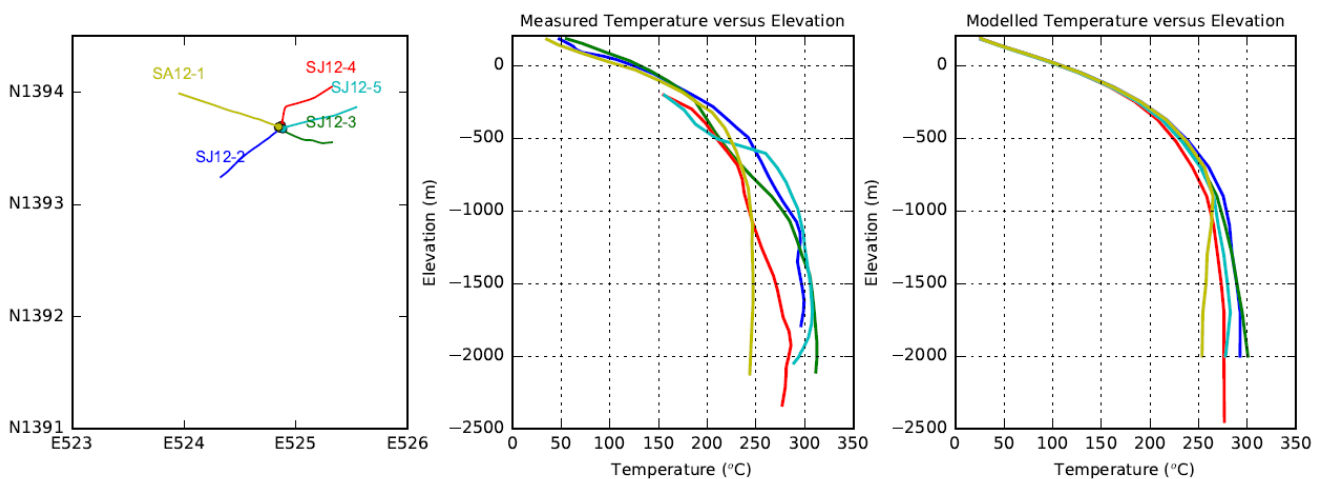


Figure 18: Measured field data compared with natural state model results for downhole temperatures from SJ12 pad wells.

The plots in Figure 19 show that the model matches the feed zone temperatures between -500 and -1,000 masl quite well for the SJ9 pad but some improvement could be made in the shallow temperatures. Currently the model is allowing too much vertical shallow flow in this area creating higher temperatures than have been recorded. This is quite challenging to calibrate because less than 500 m away from the SJ9 pad SJ5-1 shows strong shallow upflow. Also, nearby wells SJ3-1 and SJ6-1 show strong shallow upflow as can be seen in Figure 20. More calibration may be able to reduce the shallow temperatures at the SJ9 pad but it is possible higher resolution blocks may be required. However, note that the mismatch in the shallow pad SJ9 model temperatures is not expected to have a significant effect on production forecasts.

Figure 20 also shows that the model matches the variation in deep temperatures in and around the upflow very well. However, as discussed above some improvement can be made in the intermediate elevations for the more westerly wells where the model inversion is stronger than found in the observed data. This is a consequence of increasing horizontal permeability at these elevations to accommodate high production flow rates. However, it is important that the model is presently representing the trends of horizontal flows in this area. A small amount of additional calibration could resolve the temperature mismatch.

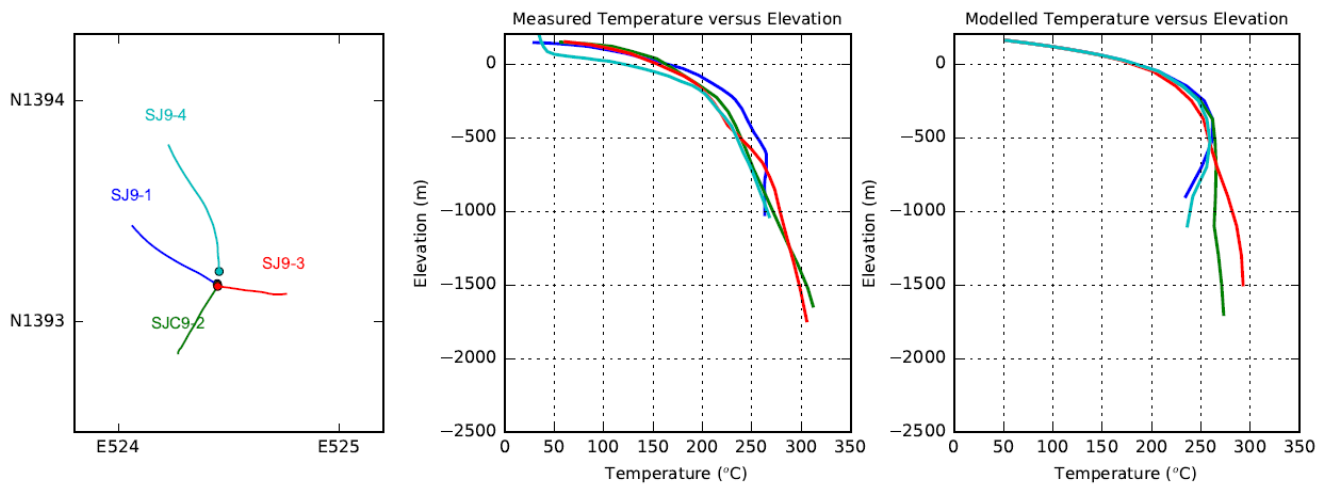


Figure 19: Measured field data compared with natural state model results for downhole temperatures from 9 pad wells.

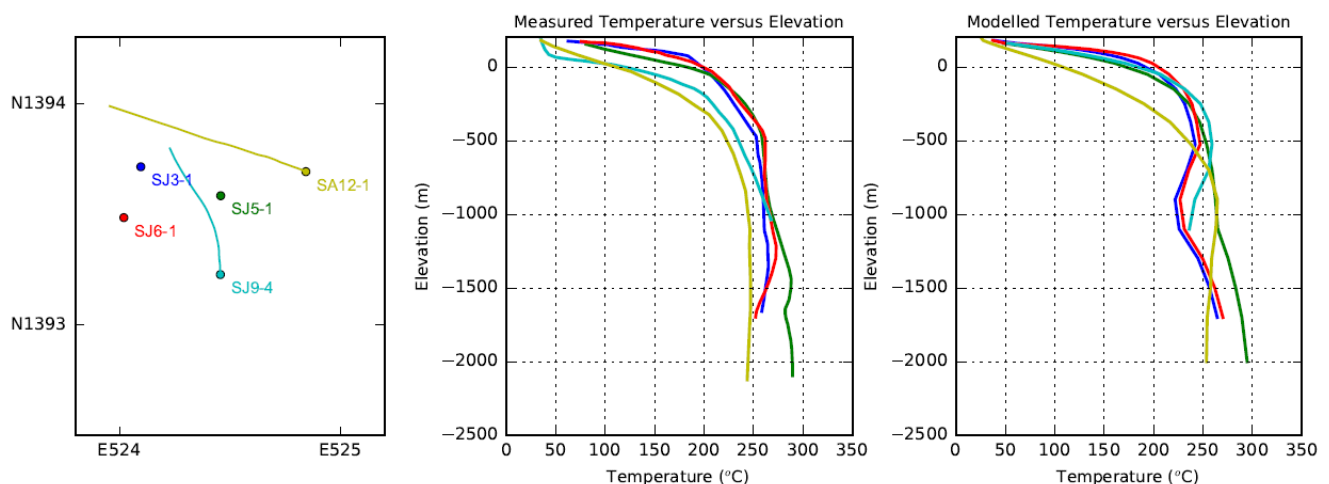


Figure 20: Measured field data compared with natural state model results for downhole temperatures from SJ3-1, SJ5-1, SJ6-1, SJ9-4 and SJ12-1.

6.2 Production History Calibration Results

The production history model was calibrated in two stages. The first stage runs from mid-2005 to late-2018 and the mass flows for both the production wells and the reinjection wells is specified. The model permeabilities, porosities and deep upflows are then calibrated to achieve a good match to production enthalpy and reservoir pressure measurements. The second stage runs for a year from late-2018 with the production wells' feedzones switched on to deliverability mode. During this stage the feedzone deliverabilities and downhole pressures are calibrated so that the model can then be run in future forecast mode. See Section 6.2.7 for more details.

Overall, the calibration of the model to the production data is very good, giving confidence in its future forecasts. The following sections present different results from the production history model and discuss different aspects of the calibration.

6.2.1 Production Totals

The plot in Figure 21 shows the model matches the forecast total steam flow very well indicating that the model representation of the average enthalpy is accurate. Two periods however show discrepancies, 2013 and 2015-2016. In the first case, the measured steam flow rate rises before the total measured production increases. In

the second case a rise in total measured production results in as slight decrease in steam flow where the model predicts an associate increase in steam flow. Both cases will be considered in more detail in Section 6.2.6.

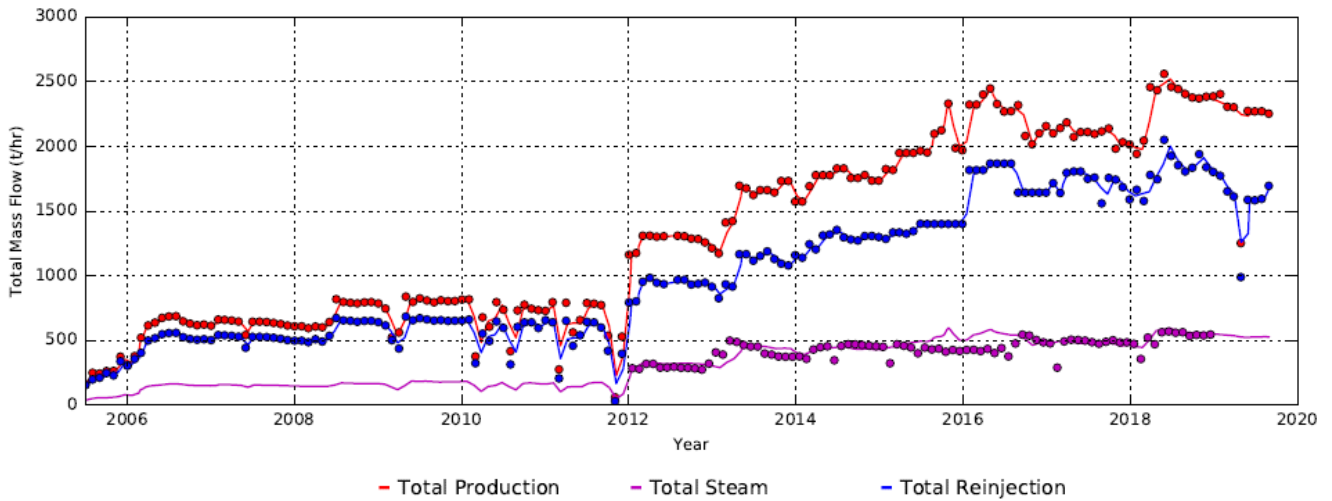


Figure 21: Model production and injection totals compared with measured data (symbols).

6.2.2 Comparisons with Conceptual Model Cross-sections in 2018

The plots in Figure 22 and Figure 23 show that the model compares very well with the conceptual model cross-sections. In both conceptual model cross-sections the temperature isotherms are compressing as pressure drawdown causes shallow boiling and encourages cooler fluid to encroach in some areas. The figures show this behaviour is captured well in the model overall. However, in both cases the model predicts the formation of a more continuous steam zone than is described in the conceptual model. To address this discrepancy higher resolution layers may be required as well as a more detailed description of the shallow geology. Figure 22 also shows that a temperature inversion at -1,000 masl that is too strong in the model is also likely to be preventing the steam zone from forming at the bottom of SJ9-1 as expected.

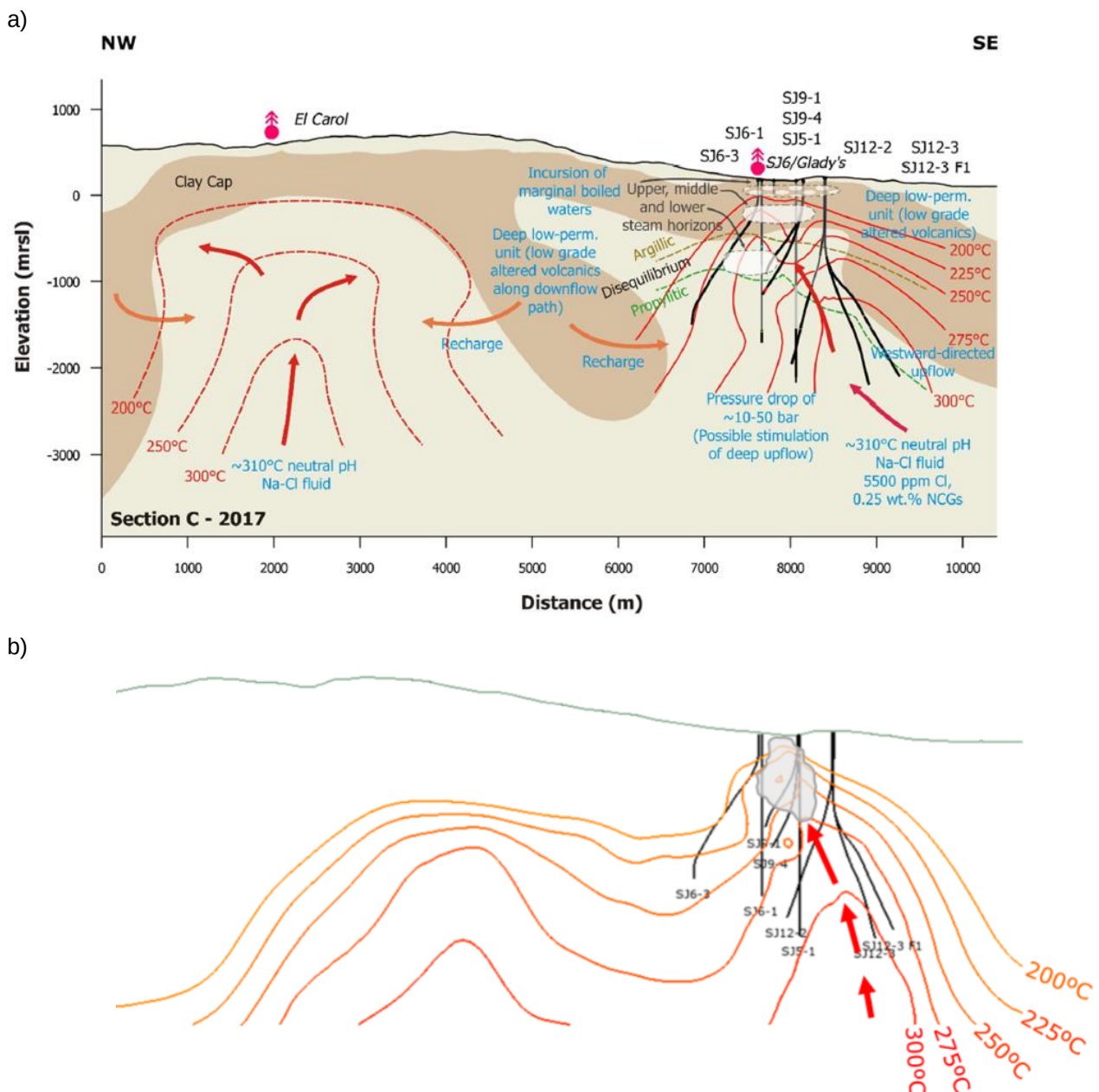
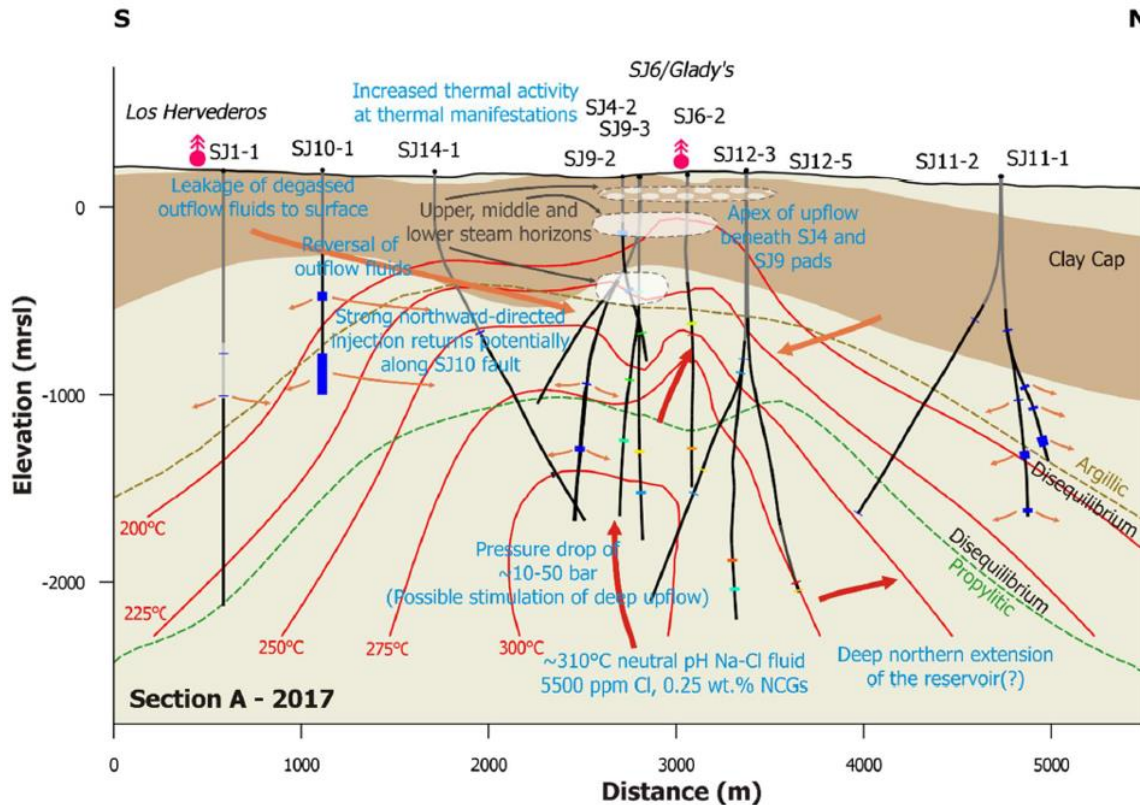


Figure 22: Comparison of (a) conceptual model E-W cross-section with (b) 2018 model temperature distribution. Model steam zone indicated in grey.

Conversely, Figure 23 shows that not enough lower temperature fluid is reaching the bottom of SJ4-2 meaning that in this zone the model is predicting higher temperatures and a deeper steam zone than the conceptual model describes.

a)



b)

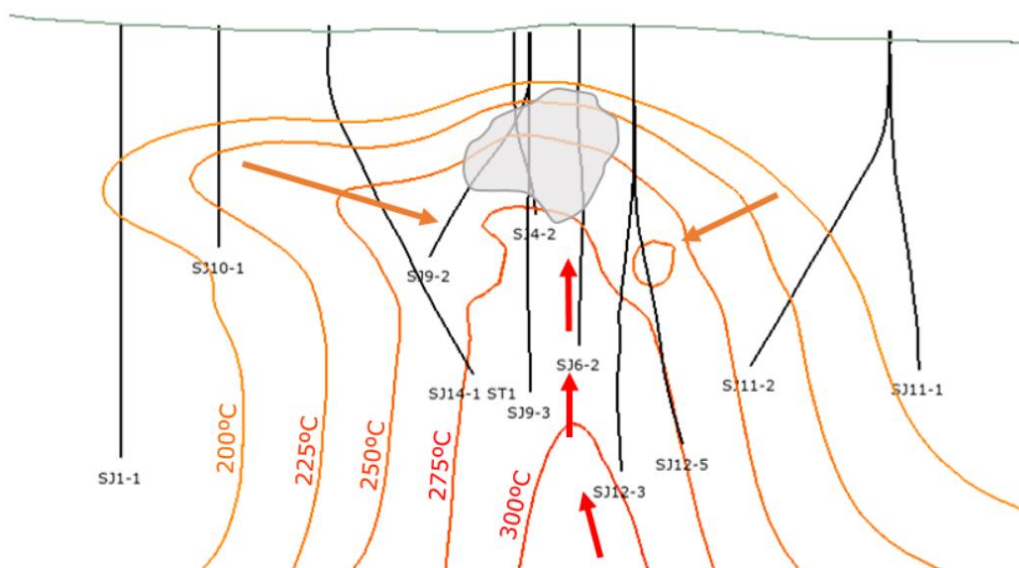


Figure 23: Comparison of (a) conceptual model S-N cross-section with (b) 2018 model temperature distribution. Model steam zone indicated in grey.

6.2.3 Evolution of the steam zone

The plots in Figure 24 show how the model simulates the evolution of the steam zone in the upper part of the production zone. The results agree with qualitative information regarding the expansion of the steam zone. They also highlight the advantage of using the air-water equation of state to model the system all the way to the surface. This modelling approach is removing the need to make imposed assumptions about the water table or the evolution of shallow temperatures and pressures. The plots also show that the steam zone is estimated to extend down ~1,000m from the surface by 2018. Finally, it can be seen clearly that the steam zone could be resolved more accurately using smaller blocks and thinner layers down into the production zone.

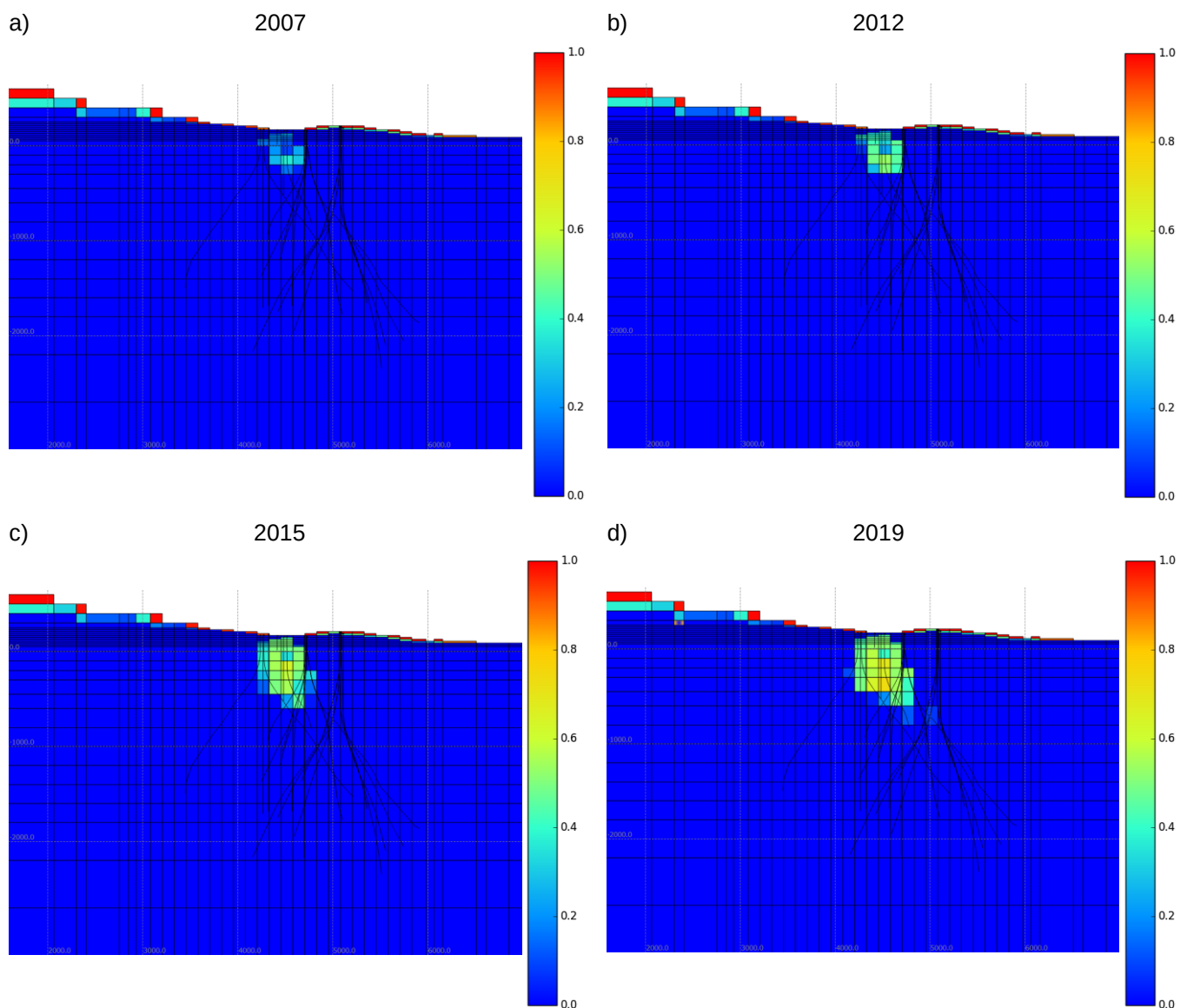


Figure 24: Model estimates of vapour saturation on an E-W cross-section through well pad 6 at (a) 2007, (b) 2012, (c) 2015 and (d) 2018.

6.2.4 Explanation of the production history plots in Appendix B

Figure 25 gives an example of the full set of production history plots provided in Appendix B for all production and reinjection wells. Plot (a) shows the wellhead and well track plotted in plan view. Plot (b) shows the model estimates of the reservoir pressures at each of the wells feedzone blocks. For some wells, such as the example of SJ6-1 below there are multiple production feedzone blocks. This may be because the well has multiple feedzones in reality, because the real feedzones extend across multiple blocks in the model, or both. The model feedzone blocks' names are given to the right of the plot and they are colour coded. The same colour codes can be used to identify the different feedzone blocks in plots (e) and (f). In plot (b) the black symbols correspond to repeated downhole pressure measurements. It is important to note the relationship between shut-in wellbore pressures and the reservoir pressures at the feedzones is complicated for multiple-feed wells. Generally, model matches in pressure are considered to be good if trends and magnitudes of change are reproduced in some of the model feedzone blocks. Note that the elevations of the model feedzone blocks are also given below the plot. Plot (c) shows the model production and injection flow rates with the model estimates of the steam flow rate included for production wells. The measured data is given as black symbols. Plot (d) shows the model estimates of the wells flowing enthalpy compared with measured data (black symbols).

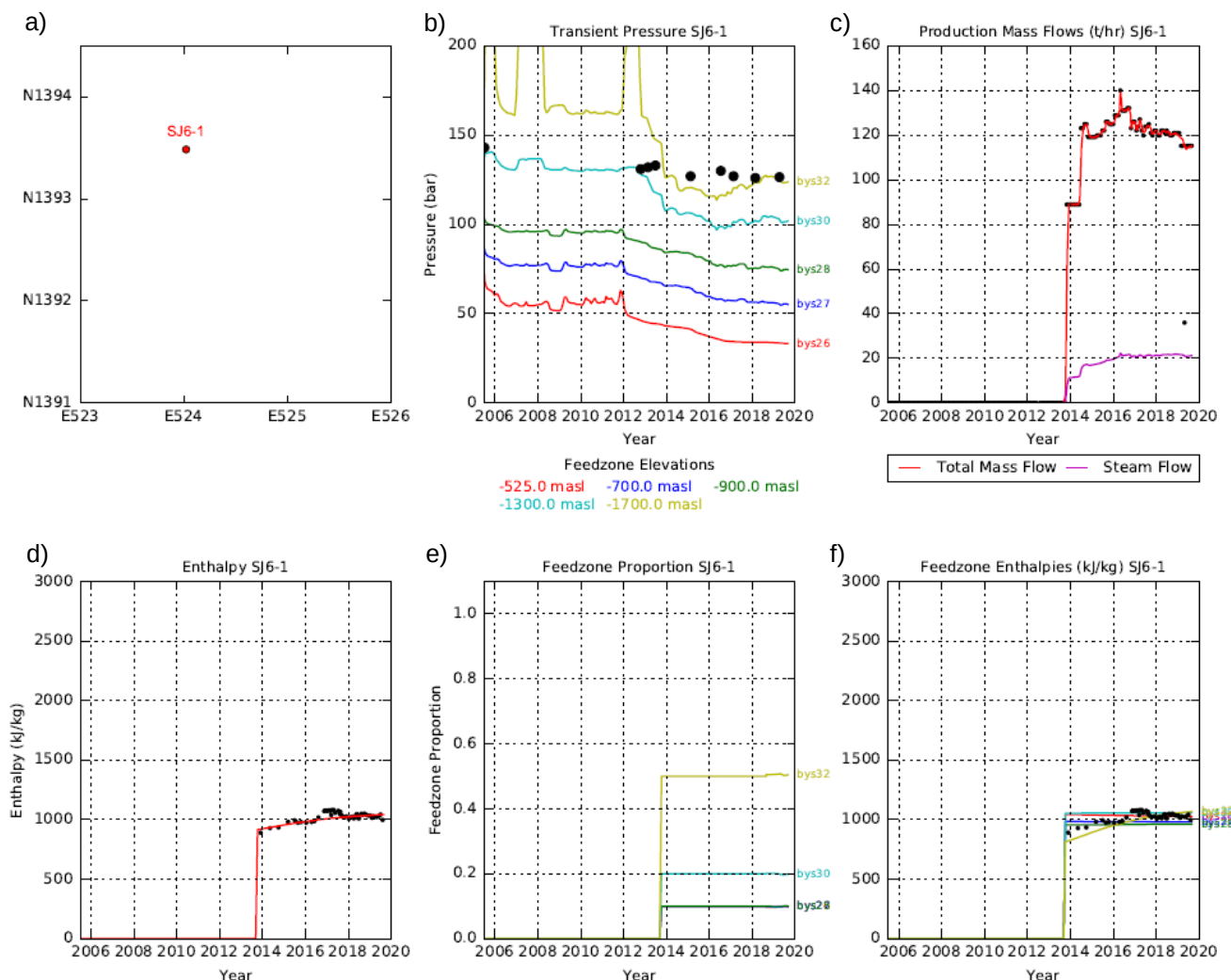


Figure 25: Example of the model output for each production and injection well provided in Appendix B.

Plot (e) shows the proportion of the total flow rate attributed to each feed zone block. These proportions can change when side tracks add new feedzones to the well or else during the final year when they are not prescribed but instead are calculated based on the well deliverability model. Finally, plot (f) shows the flowing enthalpy for each of the feedzones in the well. These enthalpies are averaged using the mass flow weighting to calculate the total flowing enthalpy in plot (d). Plot (f) can be very helpful for interpreting enthalpy changes in the well. For the example of SJ6-1 in the figure, the enthalpy is rising over time because the enthalpy in the deepest feedzone is increasing over time.

6.2.5 Pressure History Matches

The pressure history matches are shown in the plots in Appendix B for all production and reinjection wells. The table below summarised the matches and comments on each well.

Table 2: Production history pressure matches

Well	Match	Comments
SJ4-1	OK	A small amount of additional pressure drawdown is required. Slightly lower permeability could achieve this.
SJ4-2	Good	The magnitude of the pressure drawdown is matched well.
SJ5-1	Good	The magnitude of the pressure drawdown and its variation is over time matched very well.
SJ6-1	OK	The shallow model feedzones show a similar level of pressure drawdown to the measured data and the correct trends. The deeper model feedzones show more drawdown.
SJ6-2	OK	The deep model feedzones pressure drawdown is good initially but it begins recovering as its mass flow declines. Lower permeabilities could keep the deep feedzone at lower pressures and only flowing marginally as has been observed in the field.
SJ6-3	Fair	Too much drawdown in both feedzones. Permeabilities could be increased.
SJ9-1	Good	The magnitude of the pressure drawdown is matched very well.
SJ9-3	Good	A complex well with multiple feedzones but the pressure drawdown and its variation is over time matched very well by the middle feedzones.
SJ9-4	Good	The magnitude of the pressure drawdown is matched well.
SJ12-2	Good	A complex well with multiple feedzones but the pressure drawdown and its variation is over time matched very well by the middle feedzones.
SJ12-3	Good	Not much data available but a good match to the magnitude of the pressure drawdown.
SJ12-4	N/A	Insufficient data for comparison.
SJ12-5	OK	Not much data available but a reasonable match to the magnitude of the pressure drawdown.
SJ1	Good	Model injection pressures are reasonable and the trend agrees with measured data.
SJ9-4	Good	Model injection pressures are reasonable and the trend agrees with measured data. Note that early measured pressures were taken at a different elevation.
SJ10-1	Good	Model injection pressures are reasonable and the trend agrees with measured data
SJ11-1	Good	Model injection pressures are reasonable and the trend agrees with measured data
SJ11-2	N/A	Insufficient data for comparison.
SJ12-1	Good	Model injection pressures are reasonable and the trend agrees with measured data.
SJ14-2	Good	Not much data available but model injection pressures are reasonable and the trend agrees with measured data.

The modelling has highlighted significant differences between the pressure change observed in intermediate and deep reservoir feeds, notably in SJ6-2, 9-4, 12-2 and 12-3. This effect has been noted in SJ6-2 where

recent observations indicate major drawdown of the deeper feed that has led to occasional failure of that deep feed to flow, with consequent cycling. This deep pressure decline has caused some sensitivity in several wells (SJ6-2, SJ9-3 and SJ12-4 particularly), and indicates that any greater drawdown could exacerbate such well sensitivity.

6.2.6 Production Enthalpy History Matches

The production enthalpy history matches are shown in the plots in Appendix B for all production wells. The table below summarised the matches and comments on each well. Wells SJ4-1, 6-2, 9-1 and 9-3 all show small mismatches between the model results and the measured data at 2016. All of these wells predict higher enthalpies than were measured resulting in the overestimate of total steam flow by the model shown in Figure 21. Wells SJ4-1, 6-2 and 12-3 also show underestimates of the measured enthalpies in 2013 accounting for the other discrepancy in the model total steam flow.

Table 3: Production history enthalpy matches

Well	Match	Comments
SJ4-1	OK	The magnitude and timing of the enthalpy changes have not been captured. Slightly lower permeability is required and possibly a dual porosity approach and higher grid resolution also.
SJ4-2	Good	
SJ5-1	Good	The small variations around the stable trend may also be captured using a dual porosity approach and higher grid resolution.
SJ6-1	Good	The small variations around the stable trend may also be captured using a dual porosity approach and higher grid resolution.
SJ6-2	Good	Being able to vary the contribution of each feedzone throughout the production history would enable a close to perfect match.
SJ6-3	Good	
SJ9-1	OK	The decline rate is underestimated and small variations around the trend are also not captured. Improving the match may require using a dual porosity approach and higher grid resolution.
SJ9-3	N/A	The data is erratic and unreliable. Comparisons are not possible.
SJ9-4	OK	The initial enthalpy decline and the contribution from the shallow are not captured. More calibration of permeability and porosity could improve this. A dual porosity approach and higher grid resolution may help.
SJ12-2	Good	The small variations around the stable trend may also be captured using a dual porosity approach and higher grid resolution.
SJ12-3	Good	The small variations around the trend may also be captured using a dual porosity approach and higher grid resolution.
SJ12-4	OK	Slightly to low. Could be improved with a better match to hotter measured natural state temperatures.
SJ12-5	OK	Slightly to low. Could be improved with a better match to hotter measured natural state temperatures.

6.2.7 Developing a Model of Well Productivity

In order that changes of pressure and enthalpy within the reservoir can be translated into the impacts on well productivity, a model of deliverability is developed for each well, and this is complex because many wells have several feed zones. In effect, each feed zone is given a productivity relationship (defined by the Productivity Index – PI) and also a cut off pressure below which it will not flow. So, in principle this can simulate some

complex relationships such as what we see with wells like SJ6-2 that have upper and lower feed zones with very different characteristics.

The PI values and cut off pressure have been manually adjusted to achieve the flows that we see since 2018 and to achieve some correlation of the changes of flow (run down) as pressures have changed – particularly for the more recently connected wells. This calibration gives some confidence that the well productivity model will be reliable at least for modest future changes of reservoir conditions.

The productivity model is embodied within the TOUGH2 software and calculates well flows by summing the production from the feed zones for each well.

One uncertainty with calibrating the well productivity model is that it has recently become apparent that the power plant has in recent years been run in a floating pressure mode that has allowed separation pressure and turbine inlet pressure run down along with well operating wellhead pressures. This has been very sensible to sustain production from the system, but it almost certainly has been effective in “hiding” some mass flow rundown should the system have been run at a fixed pressure.

This could mean that the productivity model is actually too optimistic. The power plant is now run at what the operators consider to be the minimum safe turbine inlet pressure and so any further reservoir pressure decline could manifest more quickly as production decline. Further investigation of how the plant operation has changed and modelling of well flows would be needed to improve the productivity model for future prediction.

6.3 Current Calibration Parameters

This section presents plots showing the calibrated model parameters and discusses their implications, how they relate to the real system and some areas of potential improvement.

The plots in Figure 26 show the shallow production zone permeability and porosity distributions. Plots (a) to (c) show that the altered conductive zone identified by the MT survey has very low permeability in all directions therefore acting as both capping and confining the formation for the system. Note how the clay cap (MT conductive zone) is shallower around the main upflow at pads SJ3, 4, 5 and 6 and so there is reasonable vertical permeability shown in plot (c) in this area allowing hotter temperature to reach shallower elevations. By contrast, the SJ12 pad area is already in the low permeability clay cap and so shallow temperatures are lower. Careful inspection of the plots shows that the SJ9 pad is on the edge of the permeable upflow zone. Better matches to the shallow temperatures for the SJ9 pad wells may be achieved by reducing the area covered by the permeable zone slightly on the eastern edge.

Plots (a) to (c) also show the influence of the structural trends with east-west low permeability barriers apparent in plot (a) and north-south high permeability pathways apparent in plot (b). In plot (b) and (c) it can be seen that some low permeability pathways have been calibrated up and north-south along the structural trends even in the conductor. Physically this corresponds to the conductor not being completely impermeable to flow allowing some fluid to reach the surface which is what is observed at San Jacinto.

Note that in plots (a) and (b) there is a considerable difference in the magnitude of the permeabilities even off the explicitly represented structural trends. This shows that the model calibration required an overall anisotropy in the reservoir favouring north-south flow over east west flow. Physically this can be explained in terms of the region stress regime leading to more fracturing in the north-south direction and potentially many small structures also striking north-south.

Finally, for Figure 26 observe that the porosity is also higher in the shallow productive zone compared to the low permeability conductor. This was found to be necessary in the model to allow high production flow rates from the shallow production wells such as SJ4-1. It is not uncommon for the reservoir rock to be more porous than the surrounding rock or the altered conductor, and high porosities are typically found shallower in the system. This can result in hot fluid convection and natural state boiling just beneath the shallow conductor in the upflow zone.

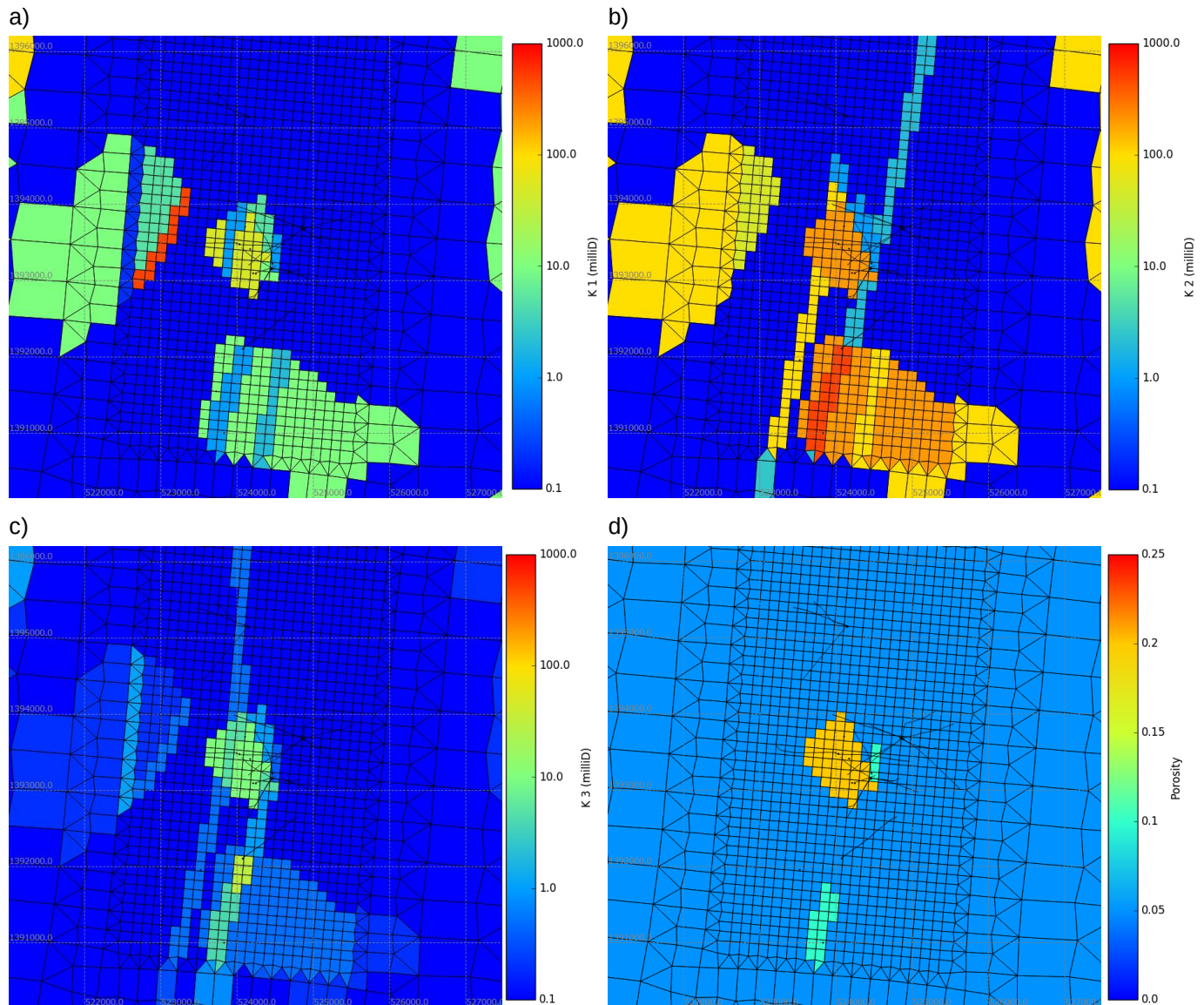


Figure 26: Model permeability and porosity distribution at -525 masl. (a) is W-E permeability, (b) is N-S permeability, and (c) is vertical permeability.

Figure 27 shows the same plots but for the main production elevation at -1,100 masl. The low permeability conductor can be seen to be bounding the system to the north in plots (a) to (c) but the reservoir zone inside is considerably larger. Plots (a) and (b) show the structural trend acting as both pathways and barriers to flow. Of particular importance note the barriers to north-south flow in plot (b) that separate the northern part of the system from the productive zone. These trends align with a number of structures that have been mapped in the past from both surface and subsurface data. While it is difficult to identify specific faults, it is clear that some structures must exist and be acting as barriers to north-south flow along these trends. This was found to be vitally important in the model to prevent significant returns from injection at the SJ11 well pad and to prevent the hot upflows spreading north.

In plot (a) of Figure 27 note the high permeability on the structural trend that SJ11-1 and SJ11-2 intercept. This trend is highly anisotropic in the model and so while it acts a barrier to flow across it, it is also a very permeable pathway for flow along it. This allows it to accept and disperse the high reinjection mass flows from SJ11-1 and

SJ11-2 while at the same time preventing the reinjected fluid from returning easily to the production zone. Plot (a) also shows the structural trends acting as barriers to east-west flow around the production zone that are consistent with the conceptual model and were found to be important for matching both the natural state temperatures and the production history data.

Finally for Figure 27 plot (c) shows that the vertical permeability is generally quite low even in the productive reservoir. The calibration process showed that this had to be the case to confine the shallow upflow to the relatively small area around pads 3, 4, 5 and 6. Physically the low vertical permeability compared with the higher horizontal permeability can be explained in terms of the layers of volcanic formations, both lava flows and tuffaceous deposits.

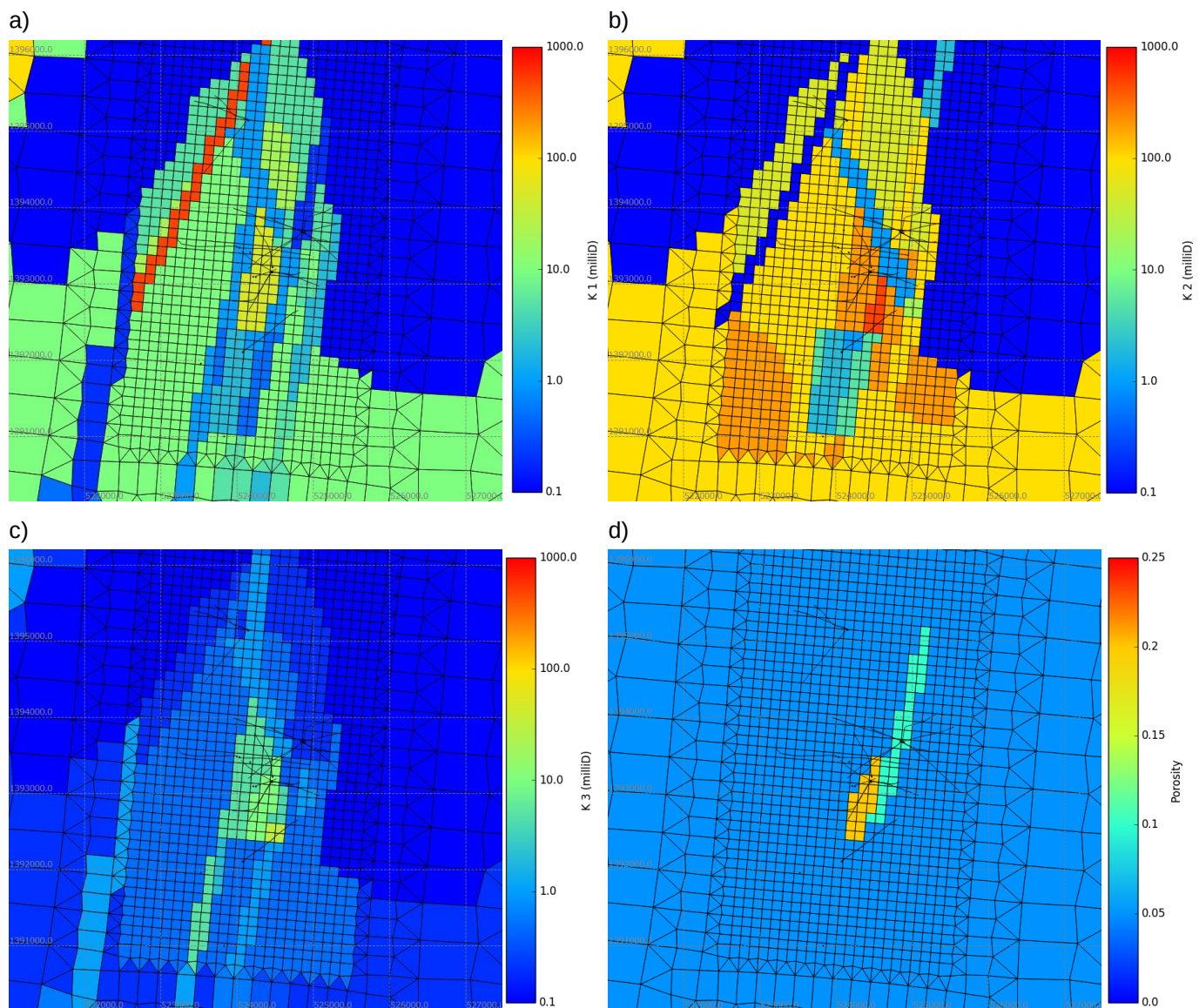


Figure 27: Model permeability and porosity distribution at -1,100 masl. (a) is W-E permeability, (b) is N-S permeability, and (c) is vertical permeability.

Figure 28 shows the deep reservoir rock properties. Plots (a) to (c) show that permeabilities are generally low as is expected. However, even in this low permeability zone the prevailing structural trend still play important roles as pathways and barriers to flow. Of particular interest are plots (b) and (d) which show that some reasonable permeability and porosity has been calibrated in the feedzone areas for SJ12-3 and SJ12-5. This was found to be necessary because of the high production flow rates achieved by both of these wells. However, the extent of this more permeable and porous zone is important for also controlling the rate of

pressure decline in SJ12-5. Currently the model predictions of pressure for SJ12-5 are not quite drawing down fast enough meaning that more calibration is required to slightly reduce the size of the region that SJ12-5 is drawing fluid from.

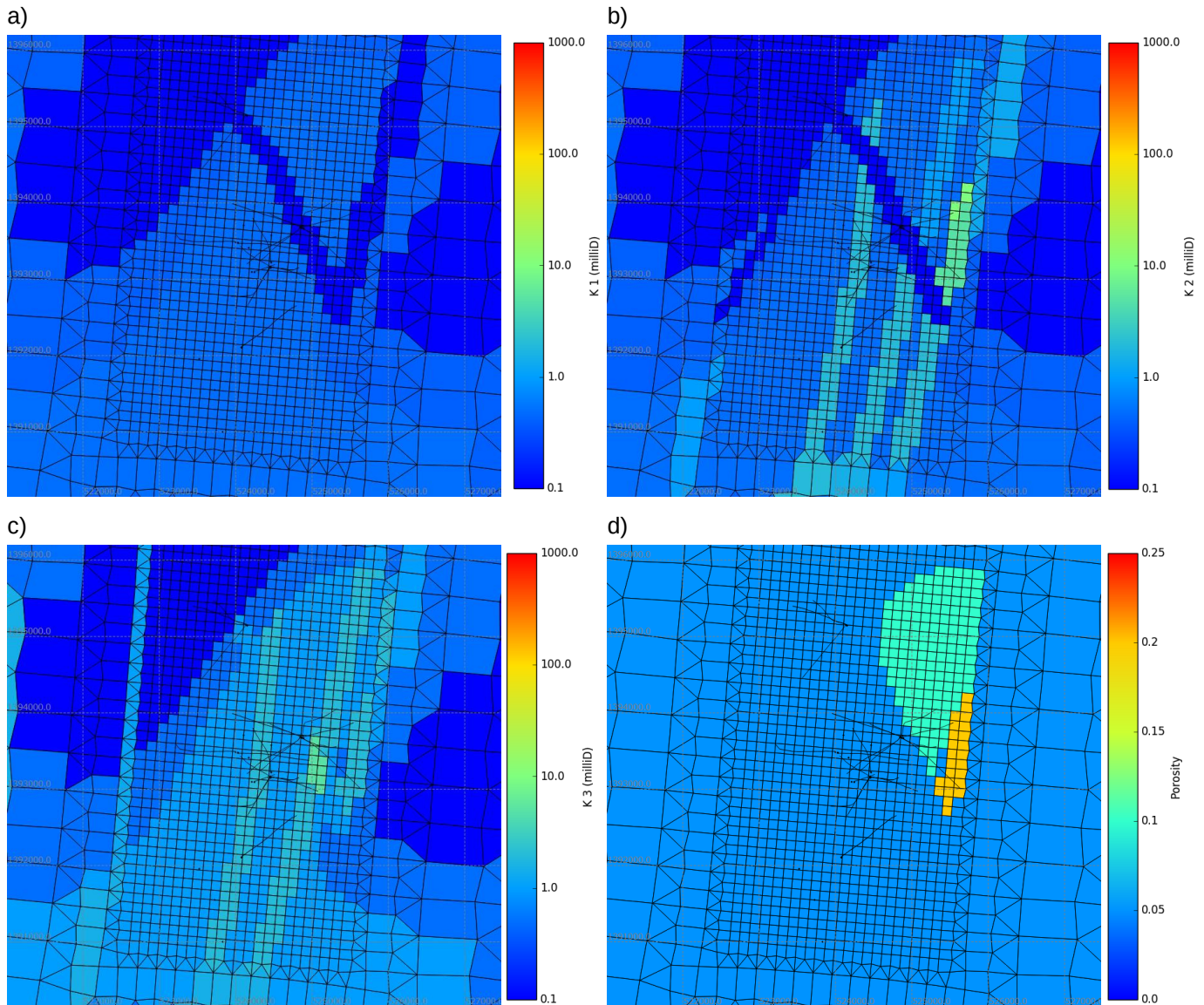


Figure 28: Model permeability and porosity distribution at -2,000 masl. (a) is W-E permeability, (b) is N-S permeability, and (c) is vertical permeability.

The cross-sections shown in Figure 29 give another perspective of the model structure and reinforce the points discussed above including the expected decreasing permeability with depth. They also clearly show the structural trends primarily dipping to the east with depth, which is another important feature of the model.

Finally, Figure 30 presents the calibrated deep upflow that is applied at the bottom of the model. It shows that the majority of the deep upflow comes from the eastern edge of the production zone, but it is transported to the production zone by the dipping structural trends. This is in line with the conceptual model. The figure also shows that a significant upflow is also applied under the Western Sector. A small amount of slightly cooler upflow (~250°C) is also applied in the central part of the system.

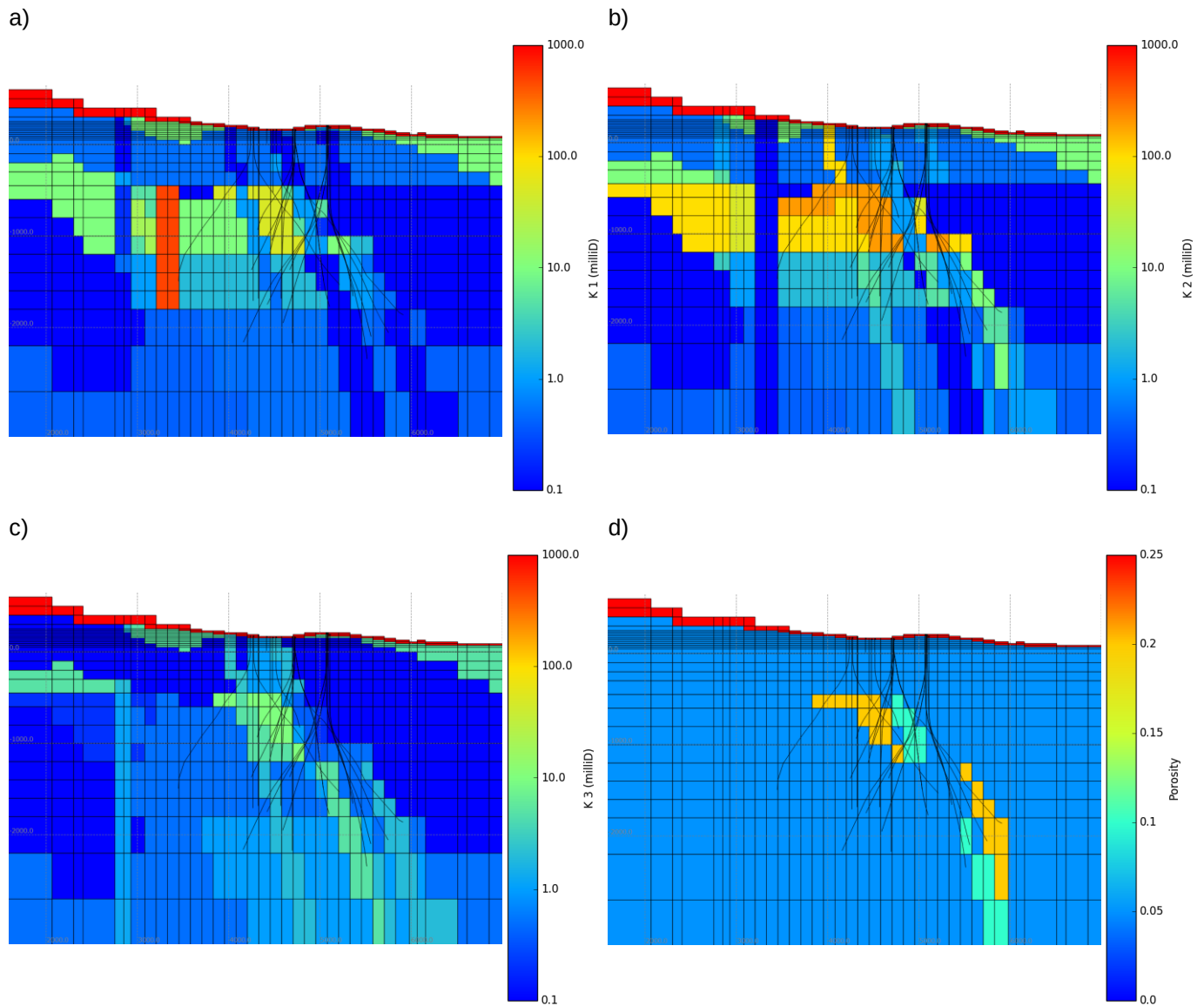


Figure 29: Model permeability and porosity distribution on an E-W cross-section through the 6 pad. (a) is W-E permeability, (b) is N-S permeability, and (c) is vertical permeability.

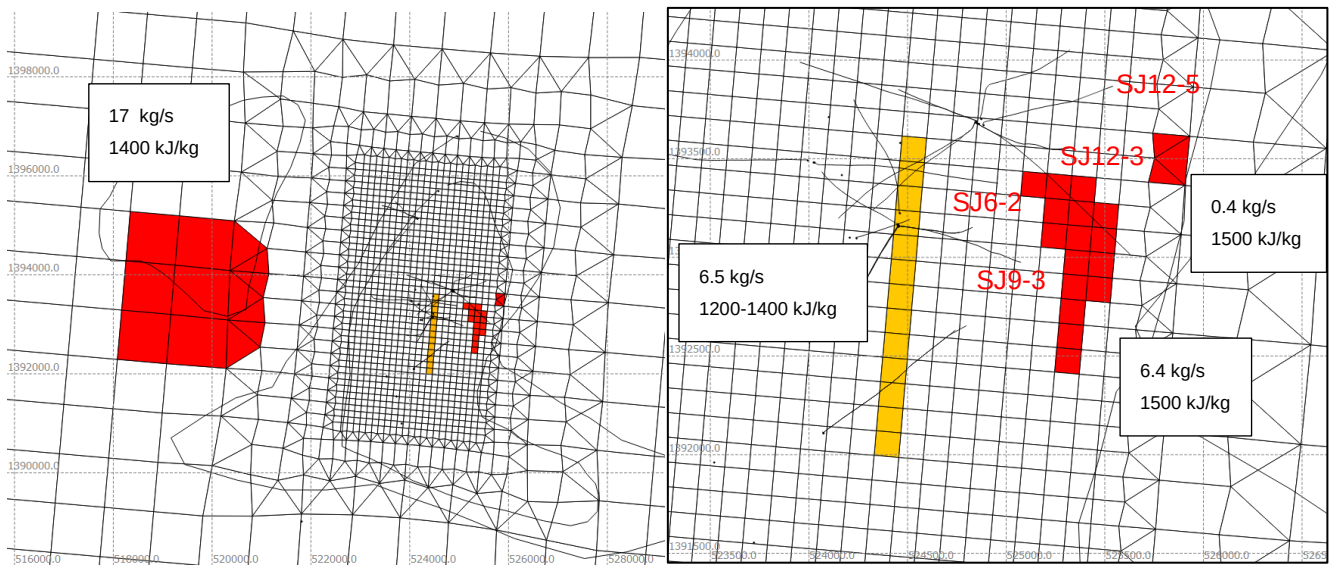


Figure 30: SJ model grid showing the location and quantity of the deep mass input in the bottom layer of the model.

7. Future Scenario Simulation

This section presents the future scenarios that have been investigated so far using the model. The setup of the scenarios is also discussed. Three future scenarios were investigated: continuing as present base case (001), more infield reinjection (002) and more outfield reinjection (003).

The main findings were as follows:

- The model indicates that the reservoir has now reached a semi-stable pressure balance between production and recharge from injection and other natural sources. This means that the present production rate from the field is projected to be surprisingly stable in future.
- Slow decline of enthalpy is the main factor that is projected to cause some reduction of steam flow (about 8-10% reduction) over the next decade.
- The present model may slightly under-estimate the sensitivity of individual wells to pressure change (because it has been calibrated while the plant operating conditions have been progressively adjusted to sustain mass flow in the face of pressure decline).
- Regardless of some uncertainties about individual well behaviour, the fundamental observation of a stabilising reservoir behaviour appears sound and do not indicate any pending collapse in the ability of the reservoir to support production.
- Over the next 10 years the benefits of pressure support from infield reinjection in scenario 002 are forecast to outweigh negative cooling effects. More specifically:
 - The model forecasts that the infield reinjection scenario 002 produces the most steam over the next 10 years with approximately 40 t/hr more than the base case 001 and approximately 60 t/hr more than the outfield reinjection scenario 003.
 - The infield reinjection wells are forecast to provide deep pressure support with only a very small negative impact on the shallow production steam zone.
- Over the next 30 years more cooling is forecast as a result of the infield reinjection in scenario 002. More work is required to optimise infield reinjection to reduce the cooling impacts over the long term.
- The present single porosity model probably provides reasonable indications of the impacts of pressure support from injection but under-estimates the cooling effects. A dual porosity model would provide a more accurate representation of reinjection return rates and should be considered for further work assessing cooling in the production reservoir.
- Pursuing some deep pressure support from in-field injection seems a prudent course of action to try and realise some of the gains predicted by modelling, but any injection wells that have high risk of creating early cooling (as evidenced by tracer returns particularly) should be used with caution.
- Optimisation of reinjection and production can be supported by investigating more scenarios using the present model but also following the recommended model refinement and conversion to dual porosity.

7.1 Simulation Setup

Once the deliverability parameters for the production wells' have been calibrated as discussed in Section 6.2, then future scenarios may be set up and run to forecast the future behaviour of the system under different operating conditions. For the current set of future scenarios, the total amount of reinjected fluid is calculated based on the total amount of production. The production fluid is separated at 5.5 bara and then the total amount of reinjection is calculated as the sum of a proportion of the separated brine and a proportion of the condensate. In each scenario the total reinjection is distributed differently among the reinjection wells to test the impact on production.

7.2 Production Scenarios

Three initial production scenarios have been run to evaluate options for future management of the San Jacinto system. These reflect the apparently competing options for injection that have been considered and debated for some time.

Because the San Jacinto system was close to boiling point for depth it has been considered that pressure drawdown could increase boiling and steam generation in the upper part of the system and actually increase well steam production instead of the decline that occurs with only liquid production. SJ4-1 has demonstrated this effect when SJ9-4 came on line. However, lateral permeability in the system seems to have allowed margin fluids and some cooling to occur which has balanced pressure decline, but we do see an expanding steam zone at several levels. This is yet to reach deep enough to have a big effect on other high productivity wells. But this approach of keeping injection away from the upper part of the system and maximising production from the upper system has been one strategy for maximising production. Stopping injection at SJ10-1 seems to be important for avoiding too much cooling and instead allowing boiling and steam zone stimulation around the SJ4-1 area and further to the north.

At the same time, it is clear that pressure drawdown in the deeper reservoir has had an impact on the production from deeper levels in the system. Injection in SJ11-2 does not seem to have any close connection to the main producing field and probably does not provide much deep pressure support. It has been considered whether more deep in-field injection could increase well production. SJ12-1 seems to present too much risk for cooling so SJ9-2 is a possible candidate for greater injection, and also SJ12-4 has been considered as a possible candidate for conversion from production to serve the injection requirements for the project.

Therefore, we have considered 3 scenarios with differing injection strategies:

- 1) Operation as at present (001)
 - Equal balance of SJ9-2 and SJ12-1, and increase injection in SJ1-1 and the SJ11- wells
- 2) Greater in-field injection (002)
 - More flow into SJ9-2. SJ12-1 and converting SJ12-4 to injection, and a little flow into SJ10-1
- 3) Greater out-field injection (003)
 - Remove all in-field injection and overload SJ11 wells

The details of injection for each scenario are presented in Table 4

Table 4: Details of the reinjection proportions of total brine and steam flow for the future scenarios

Well	Scenario 001		Scenario 002		Scenario 003	
	Base case		More Infield		Less Infield	
	Brine ¹	Steam flow ²	Brine ¹	Steam flow ²	Brine ¹	Steam flow ²
SJ1-1	20%	-	10%	-	30%	-
SJ10-1	0%	-	10%	-	-	-
SJ11-1	5%	-	0%	-	10%	-
SJ11-2	50%	-	30%	-	55%	-
SJ12-1	10%	10%	15%	10%	-	10%
SJ9-2	10%	10%	15%	10%	-	10%
SJ12-4	-	-	15%	-	-	-

- 1) Portion of total injection attributed to brine flow
- 2) Portion of total separated steam that is injected as condensate (condensate makes up about 6% of total injection)

7.3 Scenario Results

A summary of the results of the future scenario forecasts are presented in the following figures and full sets of results can be found in Appendix C, Appendix D and Appendix E. The plots in the appendices follow the same format as the production history plots as described in Section 6.2.4.

The plots in Figure 31 show comparisons of the forecast total production, total steam production and average enthalpy for the three scenarios.

The present production and injection scheme (001) is modelled to provide surprisingly stable total mass production but enthalpy decline of about 50 kJ/kg over the next 10 years has an 8-10% impact on steam production over that period. This stable mass flow results from the model indicating a present semi-stable pressure regime due to a balance of production and recharge that has now established. This stability is discussed below with SJ6-2 as an example.

Greater infield reinjection scenario 002 provides the most total steam over the next 10 years with approximately 40 t/hr more than the base case 001 and approximately 60 t/hr more than the outfield reinjection scenario 003. Comparing the individual well plots in the appendices it can be seen that scenario 002 provides more intermediate depth and deep pressure support to the production wells than either the base case scenario 001 or the outfield reinjection scenario 003. Also, scenario 002 is forecast to have a relatively limited negative impact on the shallow production steam zone and therefore the wells producing from that zone are not substantially impacted by the additional injection close to production areas.

Comparing the forecasts for the scenarios over the next 30 years in Figure 31 the picture is less clear. Scenario 002 still produces the most steam but only marginally by 2050 and it also has the largest average enthalpy decline and the fastest rate of decline for the total steam production. This indicates that the production reservoir is vulnerable to cooling from infield reinjection and that work is required to optimise infield reinjection to reduce the cooling impacts over the long term.

The scenarios indicate that although production is relatively stable, the reservoir is quite sensitive to mass flow and mass balance. Scenario 003 with lower mass balance in-field reduces overall production, and this indicates that any additional fluid take (from new wells, for example) would have a similar impact across the present production. That means trying to increase present production levels will have an impact on existing wells and may only have a small net positive impact on overall production.

While the results from the current scenarios provide useful information for helping to make operation decisions, a dual porosity model would provide a more accurate representation of reinjection return rates, the associated cooling effects and the timing of enthalpy decline in the production reservoir. This application of dual porosity is recommended in Section 8 for the next phase of modelling. Once the dual porosity model is calibrated, then the optimisation of reinjection and production strategies can be supported by investigating more scenarios using the model.

The positive impacts of pressure support apply regardless of whether the model is single or dual porosity. So, this indicates that consideration of how deep pressure support can be delivered in the system is worthy of ongoing effort in managing the San Jacinto system.

To compare between scenarios for where the impacts are manifested on typical feed zones, the plots for SJ6-2 have been selected as an example. Plots showing comparison of its forecast behaviour for the production flow rates, flowing enthalpies and feedzone pressures for both its deep and shallower feedzones are compared in Figure 32. The plots in the figures show that the deep pressure support as a result of infield reinjection in scenario 002 results in an additional 6 t/hr (~10%) compared to the outfield reinjection scenario 003 and that most of this is happening at intermediate levels in this well. Plot (c) in Figure 32 shows that the forecast enthalpy for the deep feed of SJ6-2 is very stable for the next 10 years for all three scenarios. However, the enthalpy of the upper feed is more variable. Reduced injection triggers a short-term spike of increased enthalpy indicating it is near to boiling now, but this is not long lived, and all scenarios show enthalpy decline after late 2020 and the enthalpy with scenario 002 (more in-field injection) declines faster after 2025.

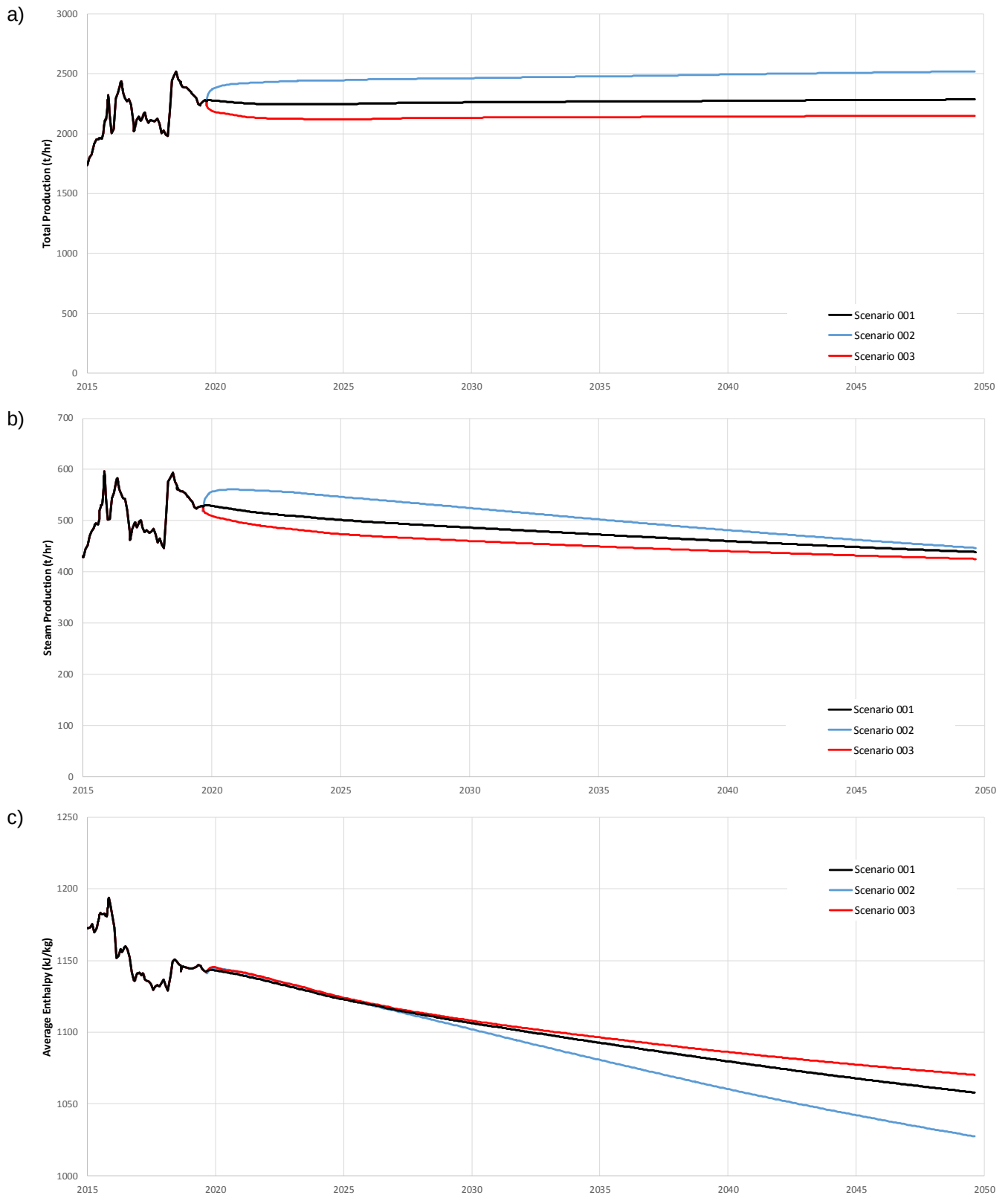


Figure 31: Comparison of model forecasts of (a) total production, (b) total steam production and (c) average enthalpies over all of production wells for the three scenarios. The increased total mass flow scenario 002 partly compensates for the greater enthalpy decline of this scenario, caused by the greater in-field reinjection.

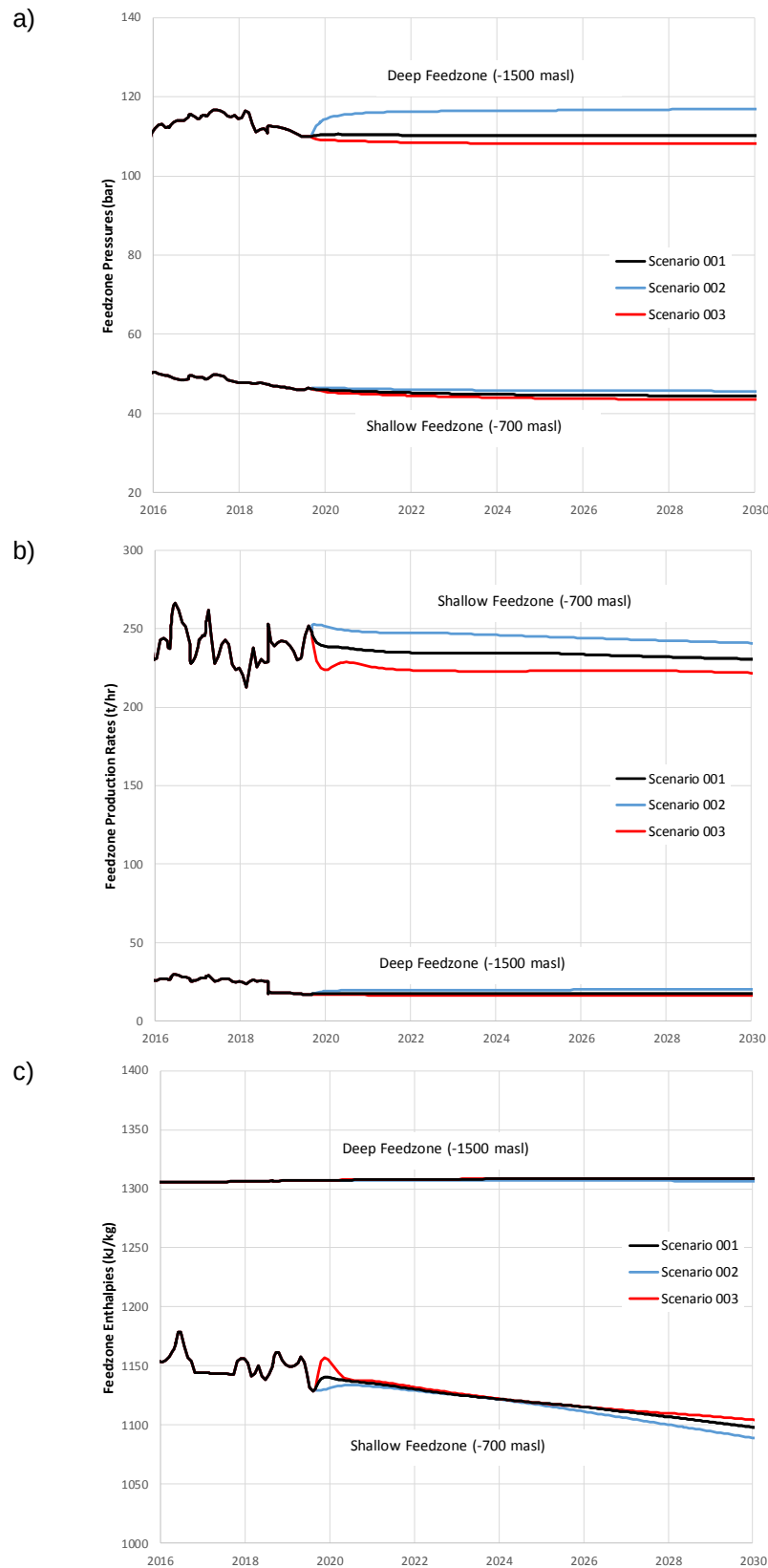


Figure 32: Comparison of model forecasts of (a) feedzone pressures, (b) feedzone production rates and (c) feedzone enthalpies for production well SJ6-2 for the three scenarios. This shows the main effects at intermediate and deeper levels of the different scenarios

The plots in Figure 33, Figure 34 and Figure 35 summarise the overall comparison between the infield reinjection scenario 002 and the outfield reinjection scenario 003. The forecast reservoir pressures at -900 masl in 2022 are plotted in plan view for the two scenarios in Figure 33. The plots show that the infield reinjection results in higher pressures through the production reservoir. They also show that the outfield reinjection increases the peripheral pressures but the permeability barriers which prevent significant returns for the reinjection at the SJ11 pad also prevent pressure support for the production reservoir.

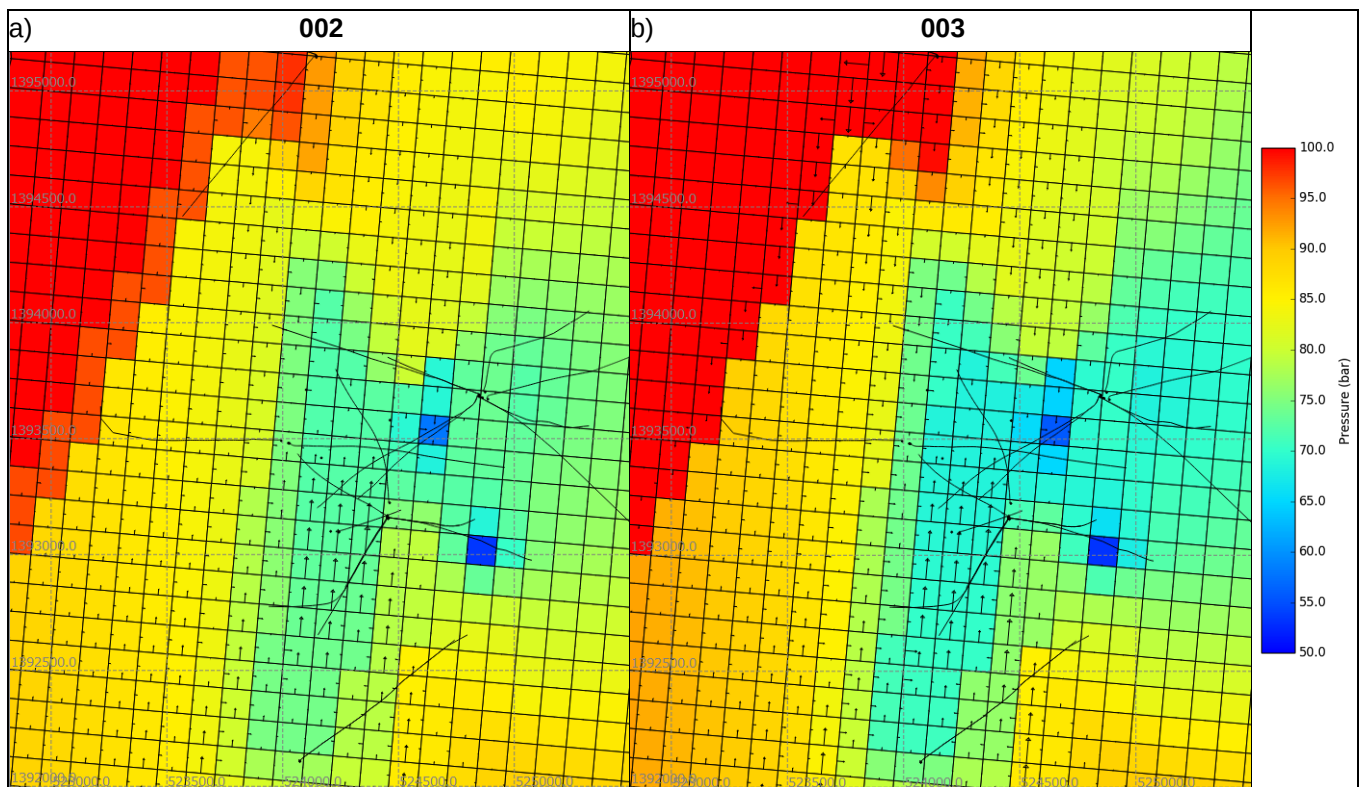


Figure 33: Comparisons of model forecasts of pressures in 2022 for scenarios 002 (a) and 003 (b). Plots are plan views at -900 masl. Arrows show the flow directions and are scaled by the flow rate. Well tracks are also plotted. Higher pressures can be observed in the main production zone in plot (a) with more pressure support from the infield reinjection. Note the high pressures in the NW sector that are supported by injection into SJ11-2, but which is modelled as being largely isolated from the main system.

In Figure 34 the forecast reservoir temperatures at -900 masl in 2025 are plotted in plan view for the two scenarios. These plots show that some additional cooling has occurred in the production reservoir in scenario 002 compared with scenario 003. However, by 2025 the additional temperature reduction is less than 10°C at this elevation in the reservoir.

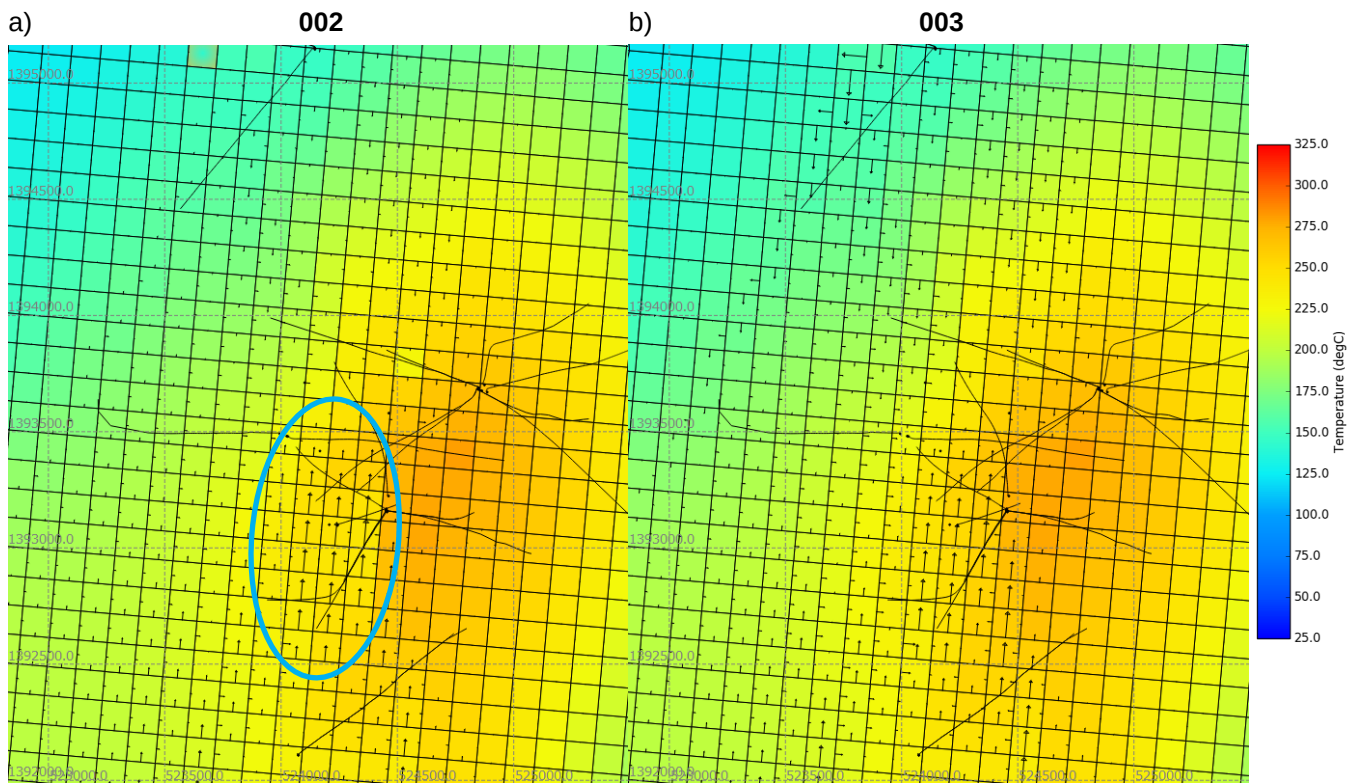


Figure 34: Comparisons of model forecasts of temperatures in 2025 for scenarios 002 (a) and 003 (b). Plots are plan views at -900. Arrows show the flow directions and are scale by the flow rate. Well tracks are also plotted. Slightly more cooling of the reservoir can be observed in the 002 scenario spreading from SJ9-2 northwards as indicated by the blue oval in plot (a). This area is about 20 °C cooler in 002 than in 003.

Similarly, the plots in Figure 35 compare the forecast shallow production steam zone for the two scenarios in 2025. They show that the small amount of additional cooling as a result infield reinjection has very little impact on the size of the shallow production steam zone. This is largely because the infield reinjection has been targeted at deeper and hotter feedzones therefore limiting the impact on the shallow production zone.

Comparing the cross-sections, it can be seen that the bottom of the shallow production steam zone is forecast to be slightly higher in scenario 002 compared to scenario 003. However, this is mostly a result of increased deep production pressures in scenario 002 rather than additional cooling reducing the amount of boiling.

The steam zone does not expand very laterally in any scenario, probably indicating the balance between pressure and marginal cool recharge. In scenario 003 the enthalpy of SJ4-1 and upper levels in SJ9-1 show a limited period of higher enthalpy before enthalpy declines after 2021. This indicates that even reduced in-field injection does not cause the steam zone to continue expanding.

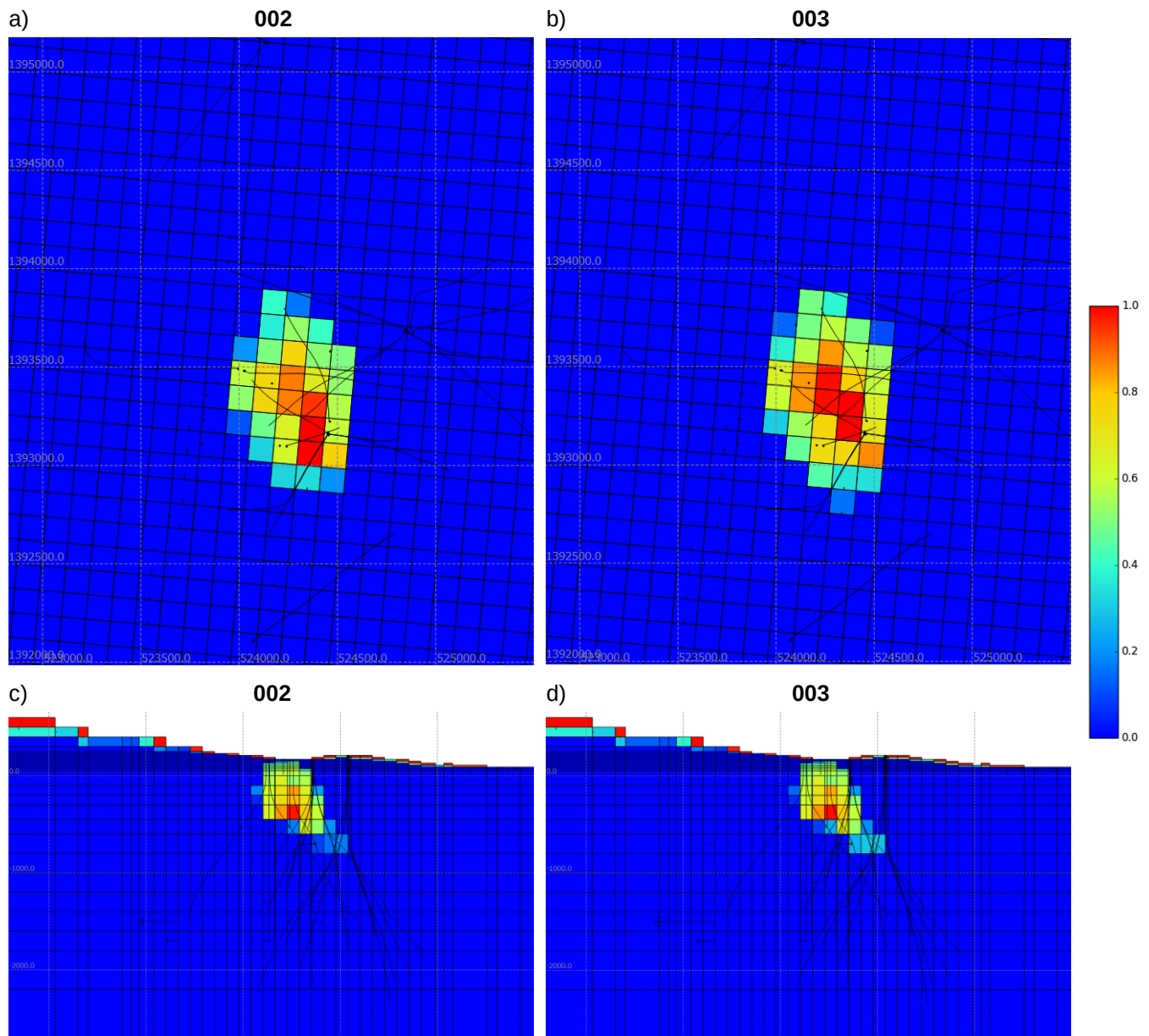


Figure 35: Comparisons of model forecasts of vapour saturations in 2025 for scenarios 002 (left) and 003 (right). Plots (a) and (b) are plan views at -375 masl and plots (c) and (d) are E-W cross-sections through the SJ6 pad. Well tracks are also plotted. The plots show that scenario 002 has a slightly smaller boiling zone with slightly lower vapour saturations. The largest difference is that the boiling zone does not extend as deep in scenario 002 as it does in scenario 003.

8. Recommendations for Future Modelling

The numerical reservoir model is now reasonably calibrated for the purpose of understanding present behaviours and predictions of gross behaviour of the system. However, the following are aspects that can be considered for ongoing improvement as a tool for assisting the management of the San Jacinto geothermal reservoir going forward.

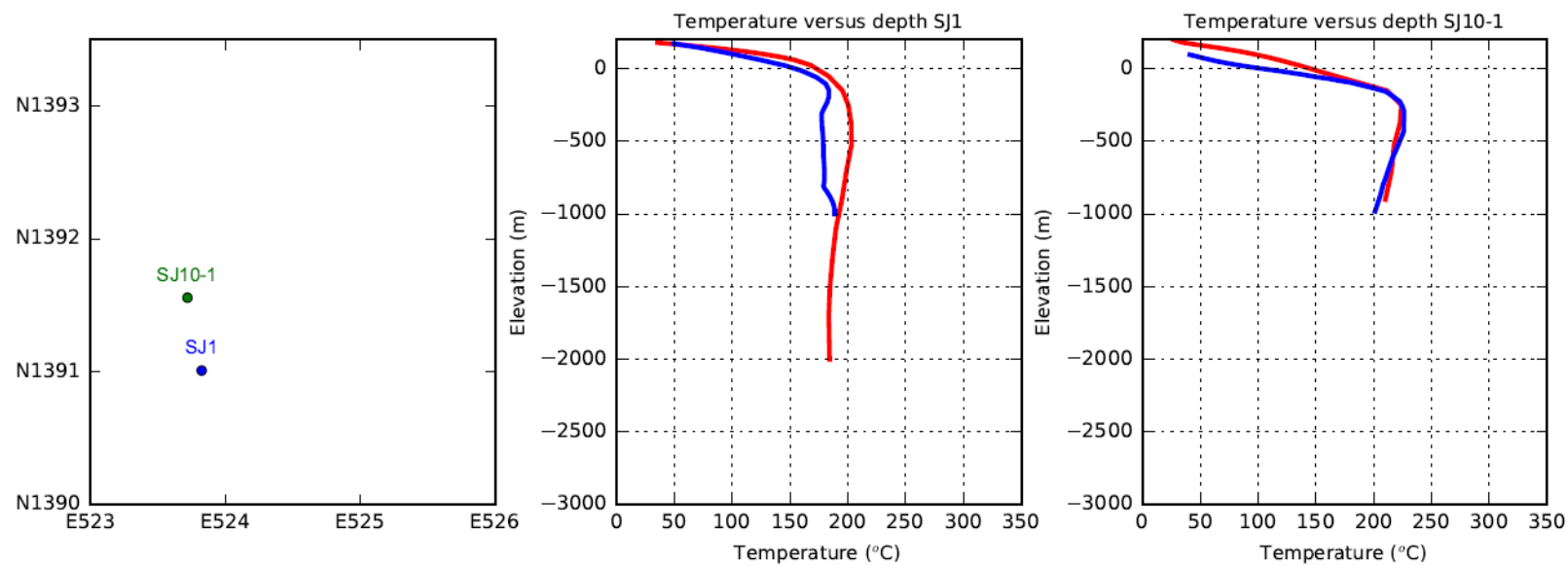
Aspect	Opportunity	Requirements
Natural State	Improve N-S temperature matches, which should result in improved permeability structure, and assist initial enthalpy matches under production	Another iteration of considering permeability and how it affects temperatures.
Production History	Improve transient enthalpy matches including better representation of declines due to reinjection returns	This will require the implementation of the dual porosity model. Conversion to the recently developed Waiwera software advised for this process.
Shallow steam zone	Steam is already generally present in the upper model because of boiling, but explicit matching of the identified shallower zones (particularly that at 300 m) may help determine how much production could be achieved.	Refine shallow permeability and calibrate to inferred pressure changes at these levels.
Tracer test matching	The tracer flow dispersion and travel time / volumes can be modelled more explicitly. This will improve the predictive ability of the model for assessing the thermal effects of injection.	This will require the implementation of the dual porosity model. The tracer data can be used as additional calibration data for the dual porosity model. Conversion to the use of the new Waiwera approach advised.
Well deliverability	Calibrate well deliverability to better handle the varying wellhead pressure that has been allowed in recent years. This should provide better predictive behaviour of individual wells.	Extract more detailed well operation data (wellhead pressure and flows) and calibrate individual feed productivity indices using simplified wellbore models.
Conversion of the model from AUTOUGH2 to Waiwera	Waiwera is a new, free, open-source geothermal reservoir simulator developed at the University of Auckland, Geothermal Institute. It simulates geothermal systems in exactly the same way as AUTOUGH2 but its parallel processing capability means much faster run times and therefore faster calibration.	This model phase was retained in AUTOUGH2 for continuity and transfer to PENSAs, but Waiwera has now been made publicly available and will be a viable option for continued modelling. AUTOUGH2 models can be converted to Waiwera models easily and comparison are simple to carry out.
Uncertainty quantification in forecasts	Technology is now available enabling forecasts of quantities such as total steam flow to be made including 95% confidence intervals making decisions based on those forecast more robust.	These types of complex forecasts are much computationally intensive and therefore more costly and time-consuming. However, given the benefits of the additional information they provide they should be considered.

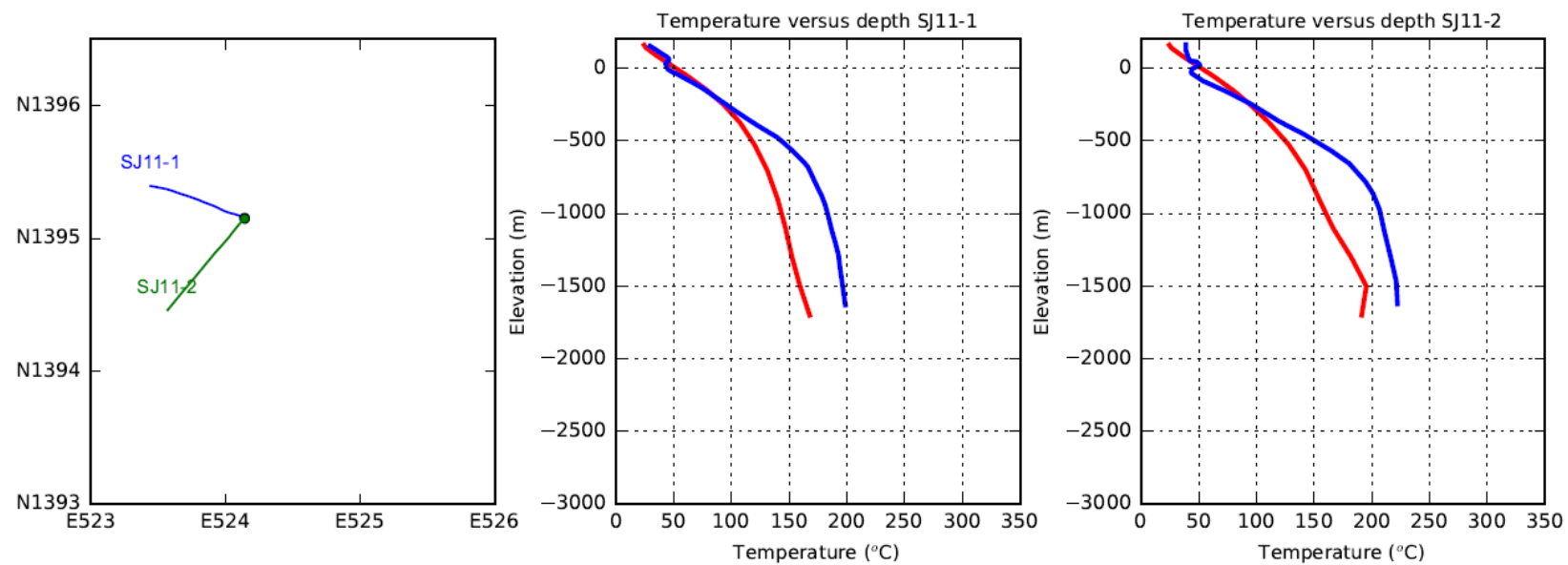
9. References

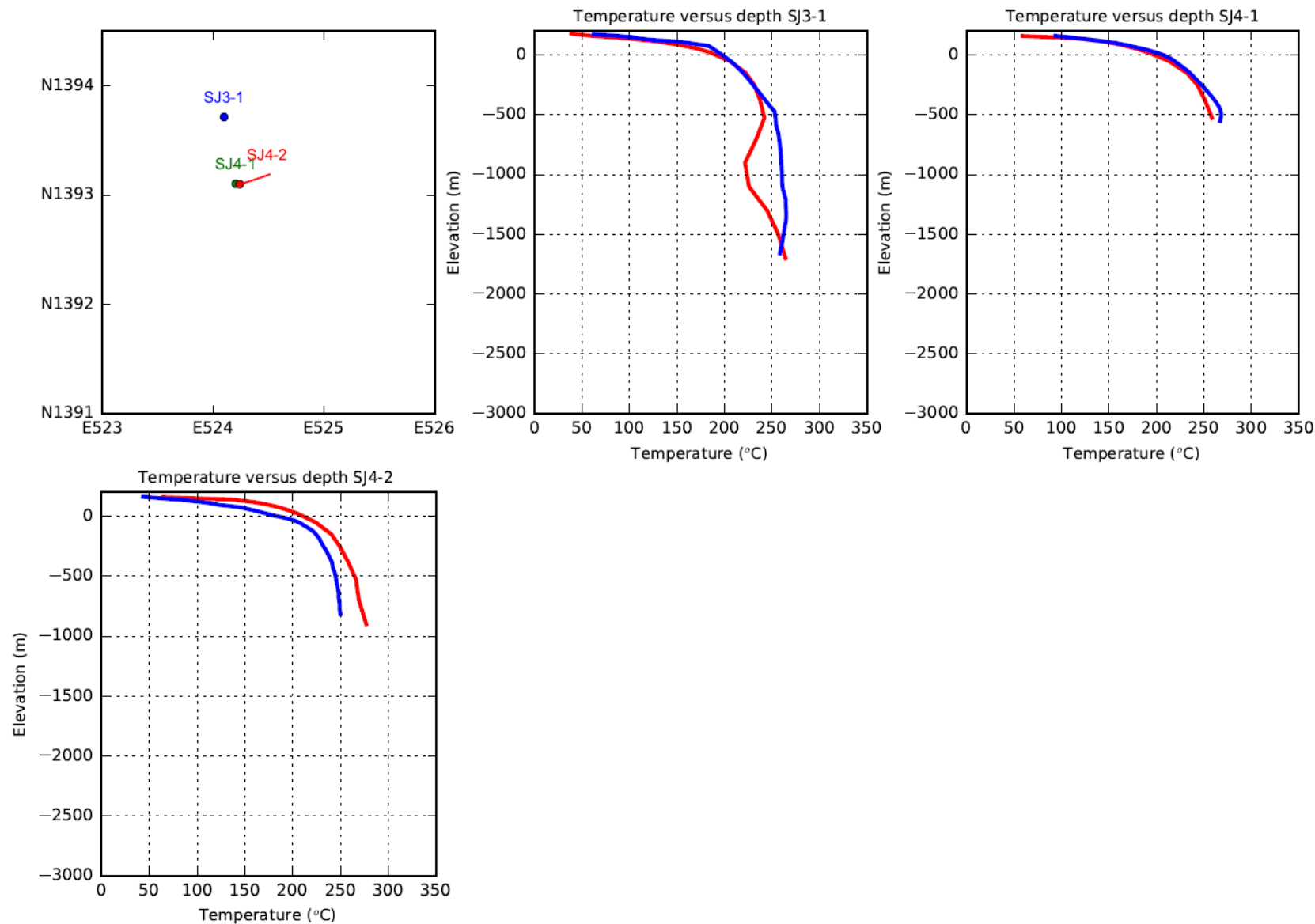
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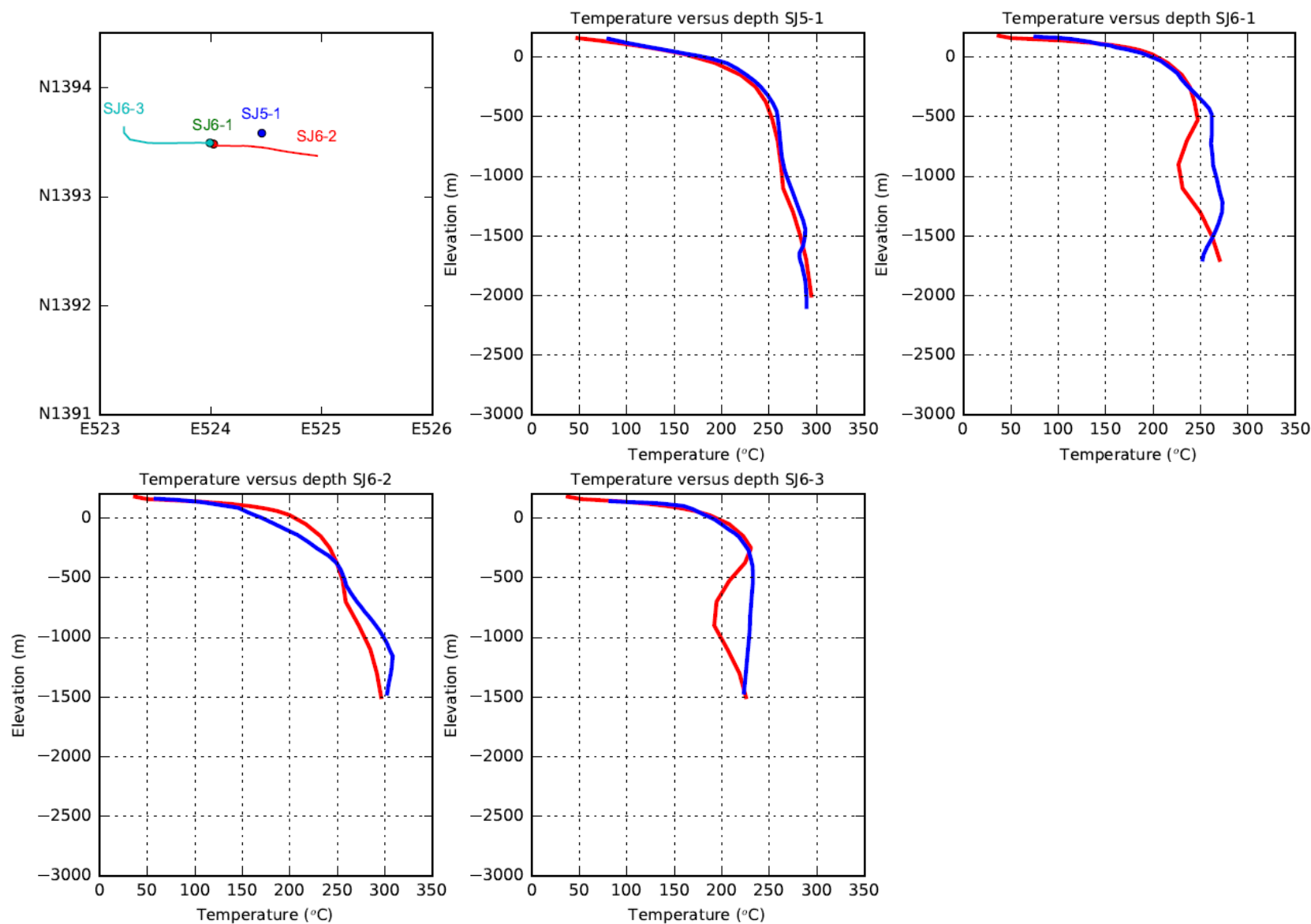
O'Sullivan, J. P., Croucher, A. E., Popineau, J., Yeh, A., & O'Sullivan, M. J. (2019). Working with Multi-million Block Geothermal Reservoir Models. *In Proc. 44th Workshop on Geothermal Reservoir Engineering*. Stanford University, Stanford, California, USA.

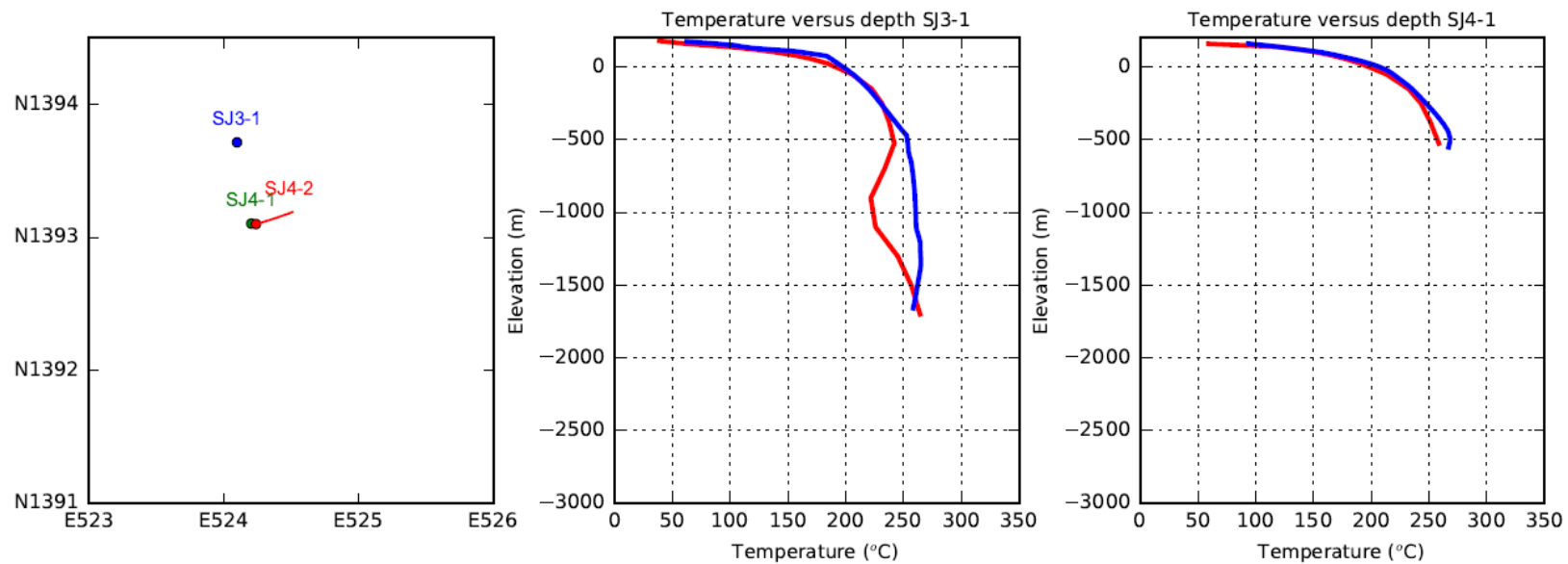
Appendix A. Natural State Downhole Temperature Comparisons



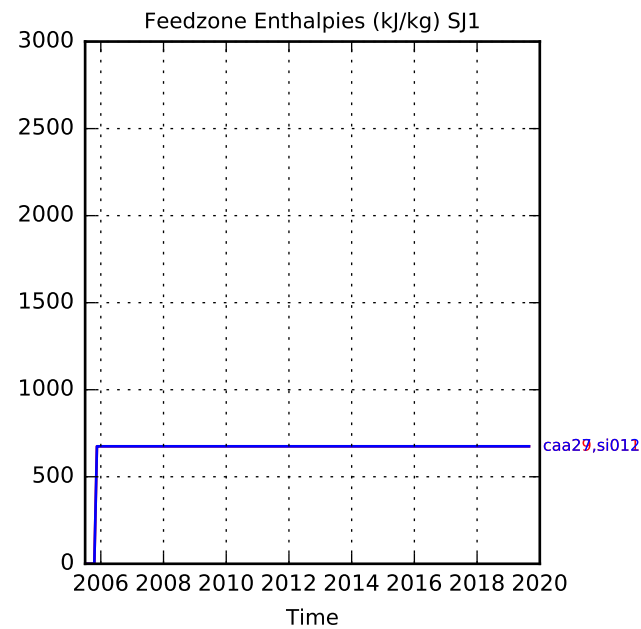
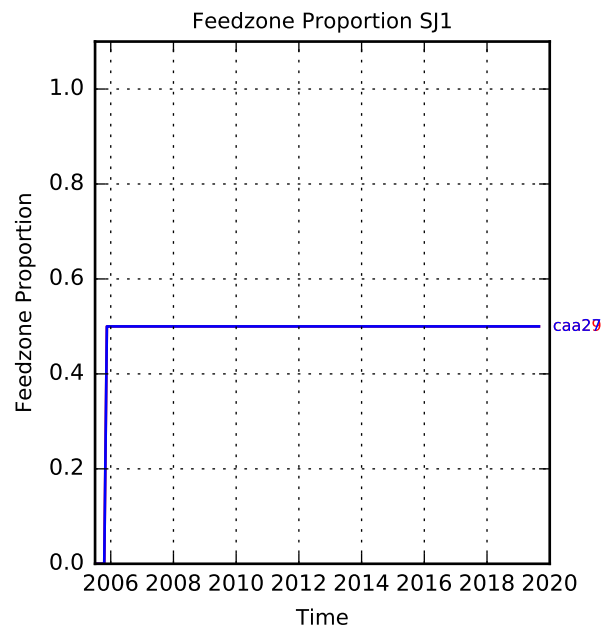
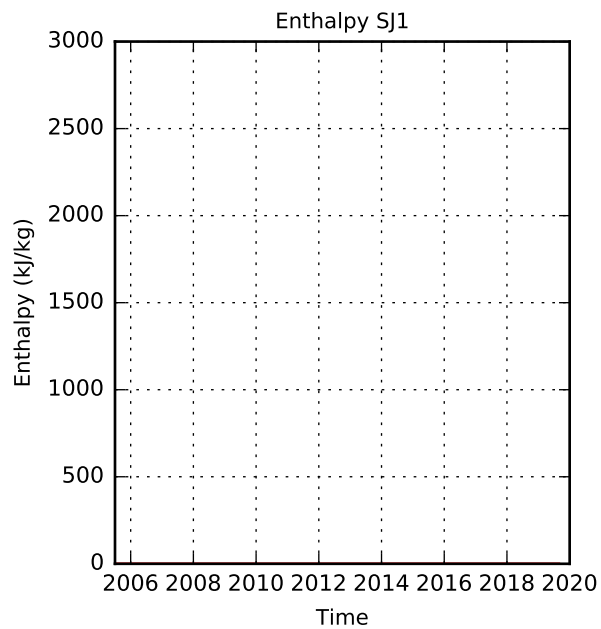
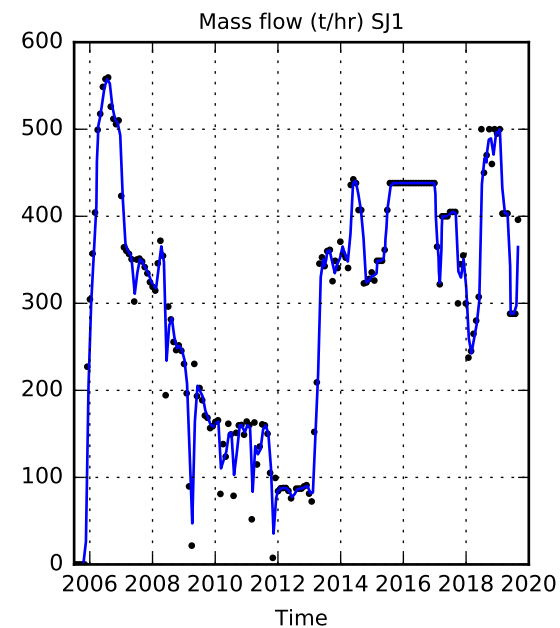
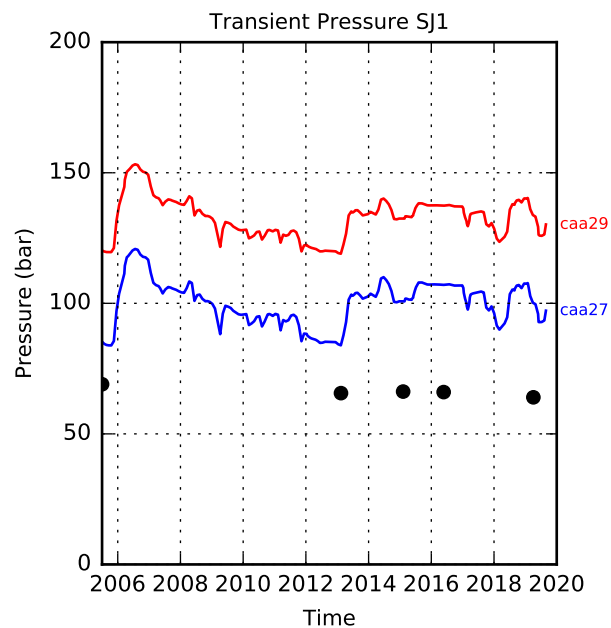
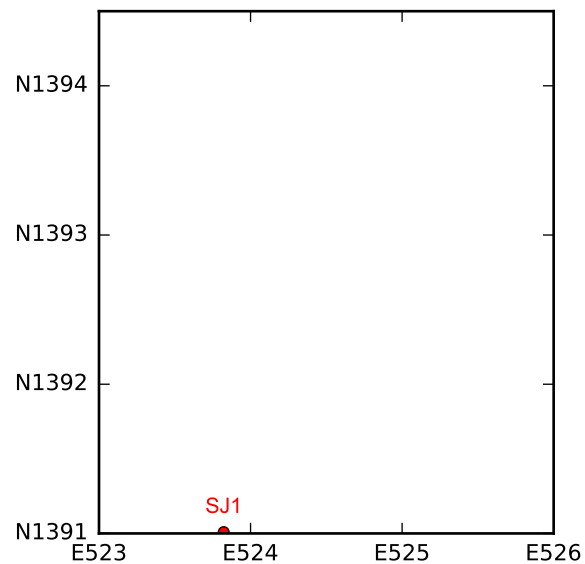


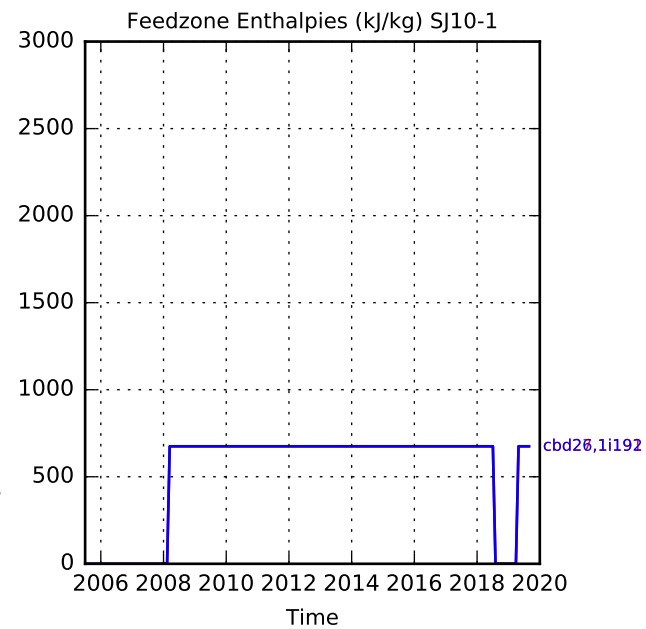
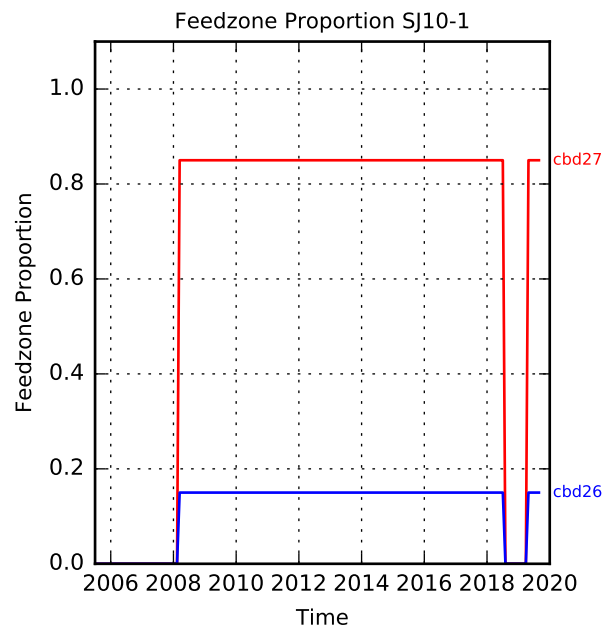
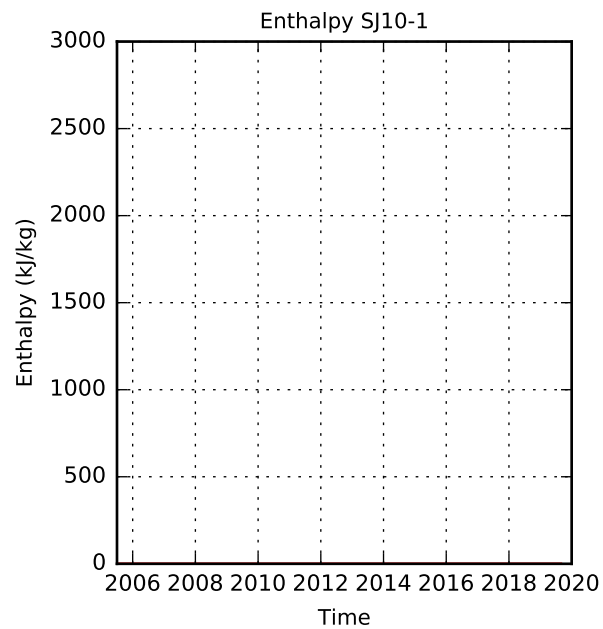
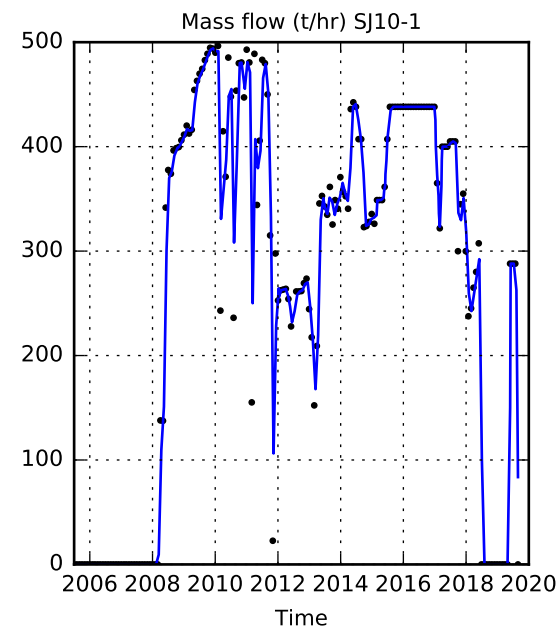
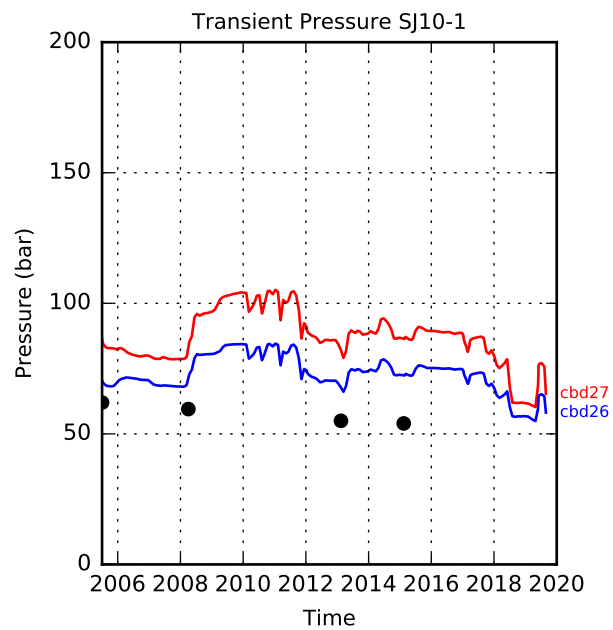
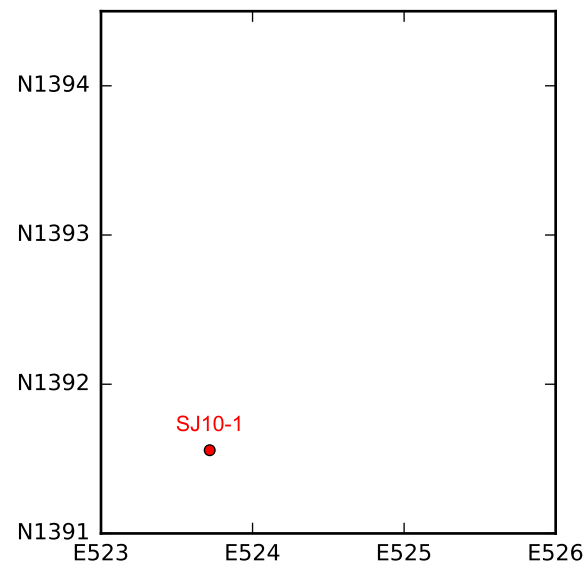




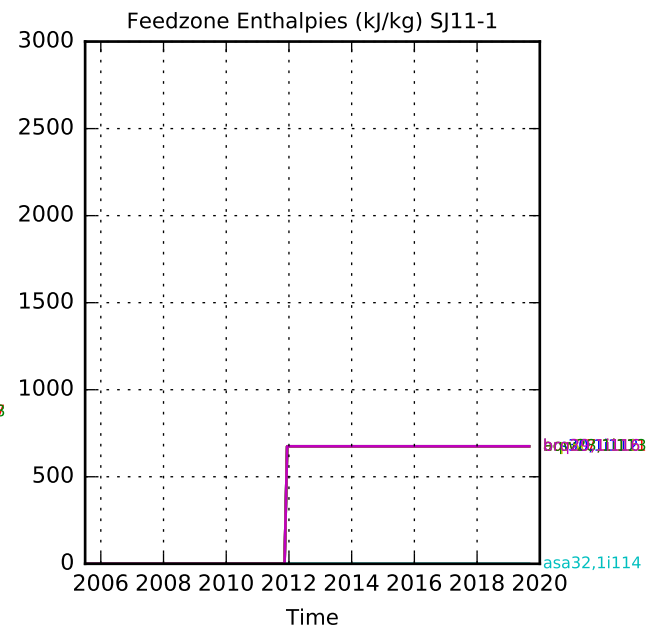
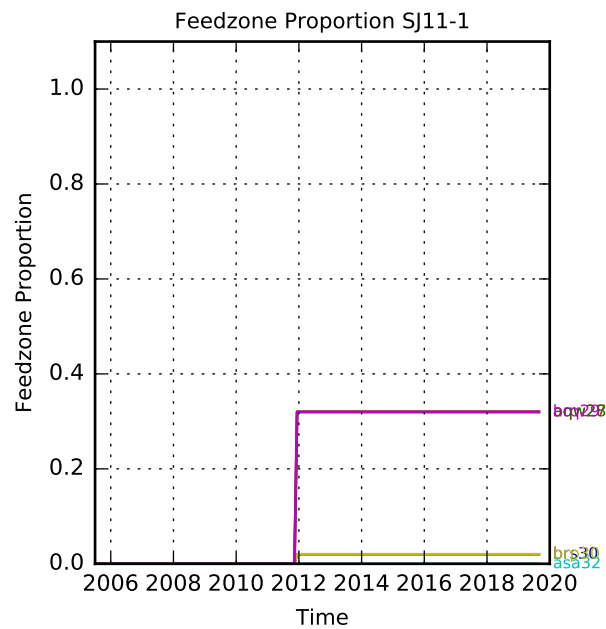
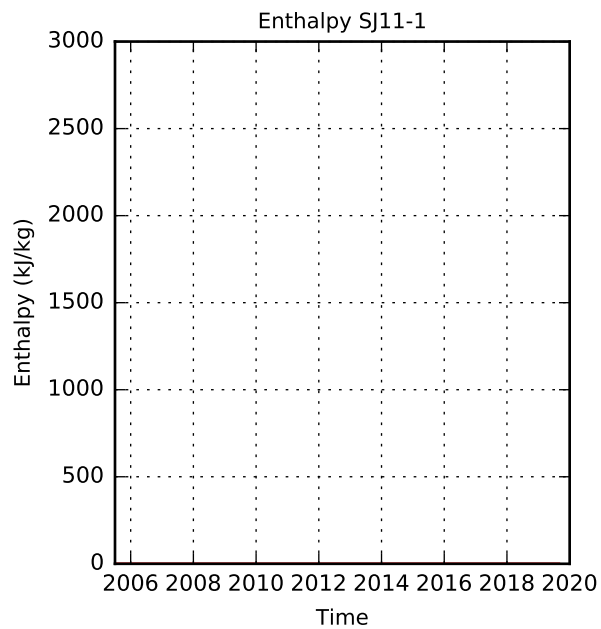
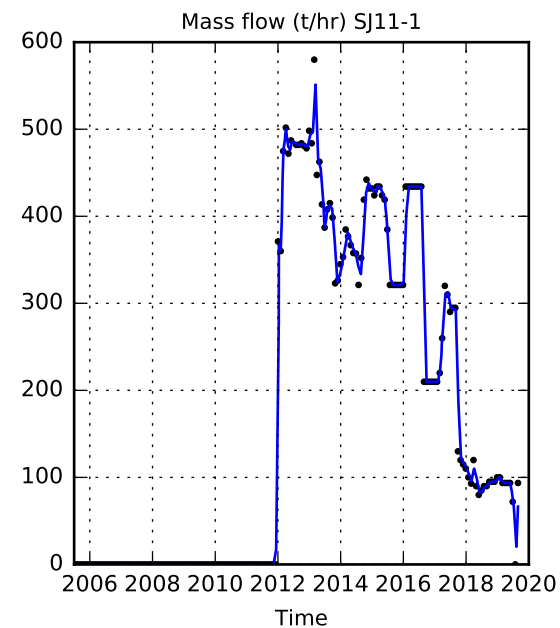
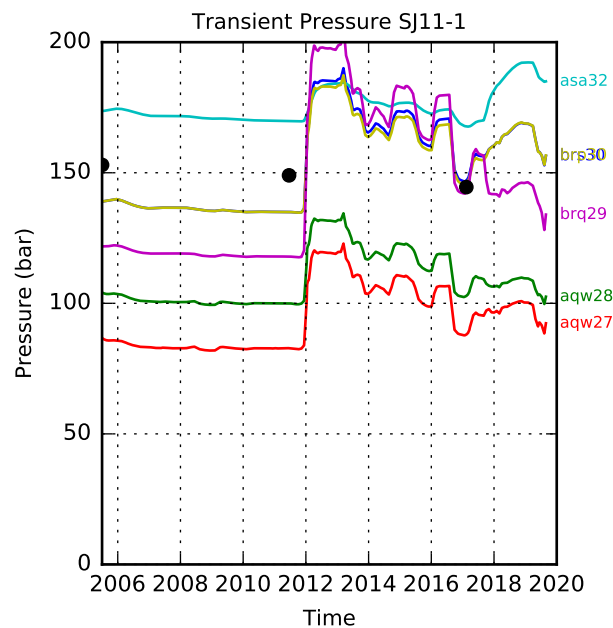
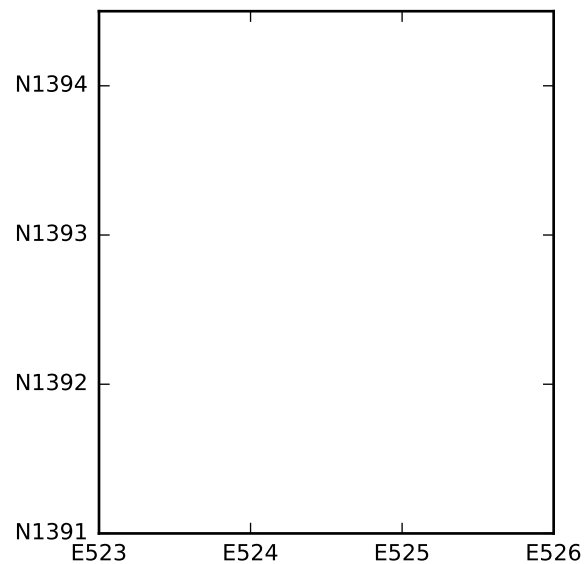


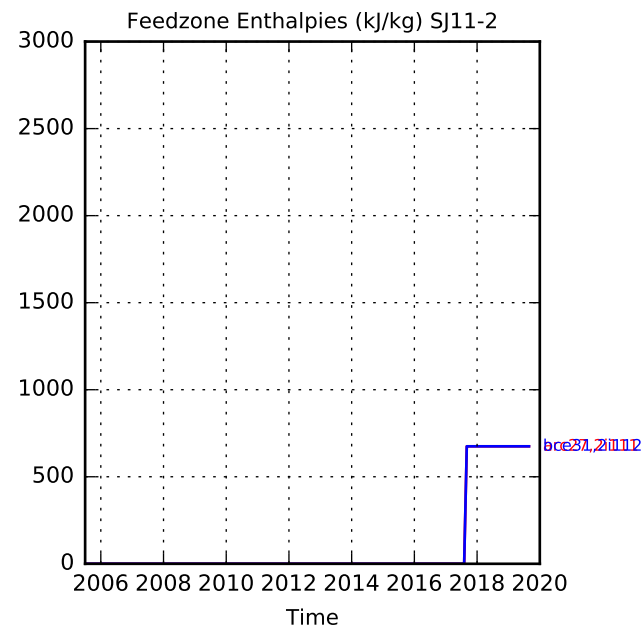
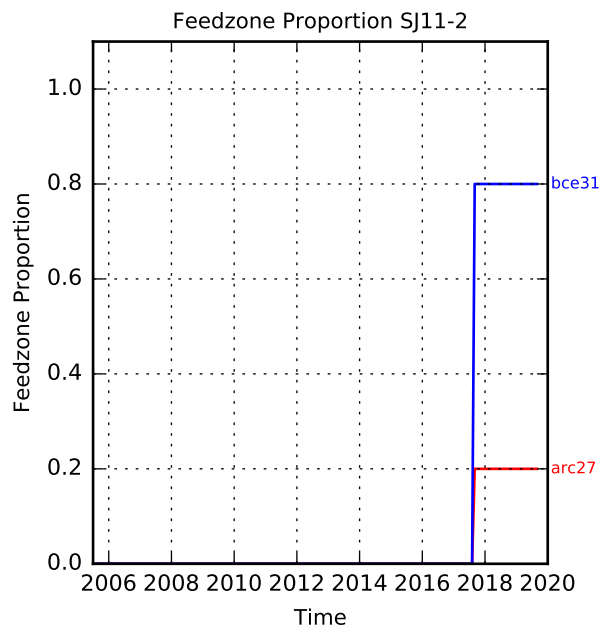
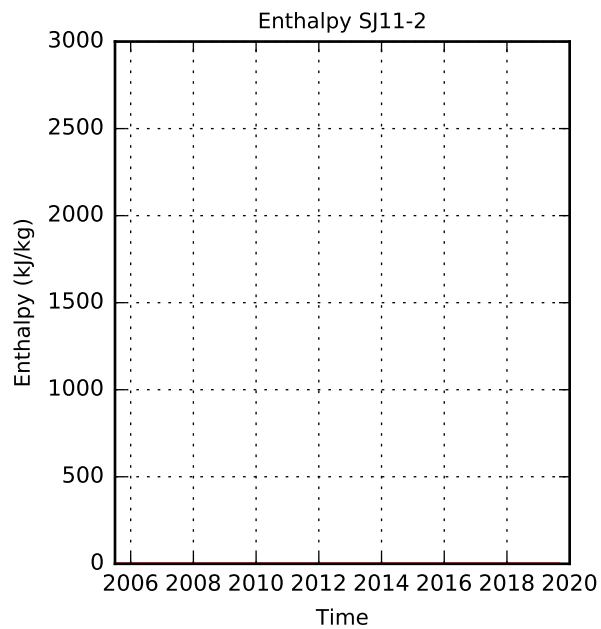
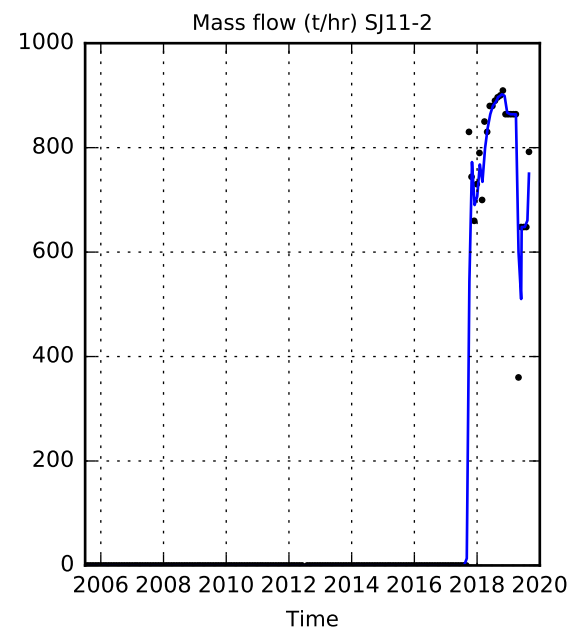
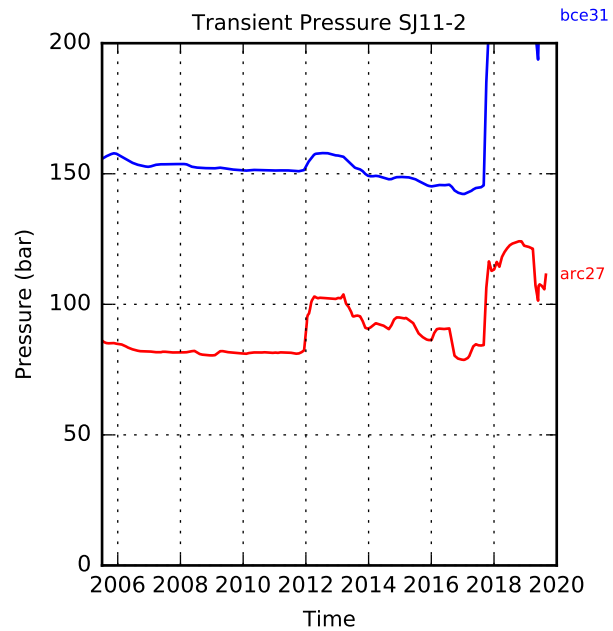
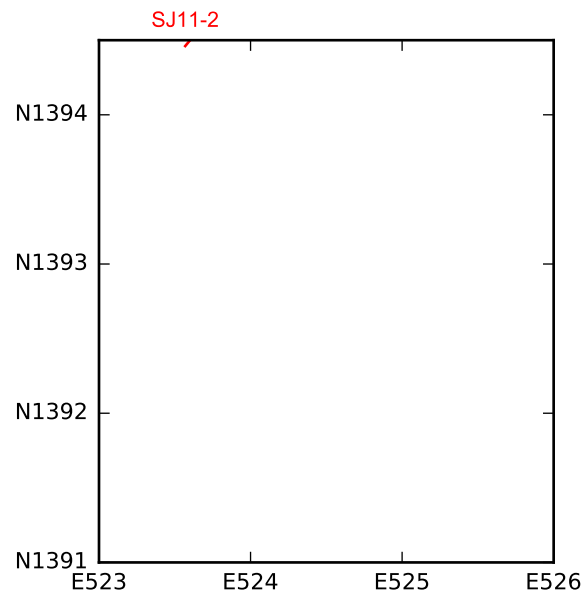
Appendix B. Production History Comparisons

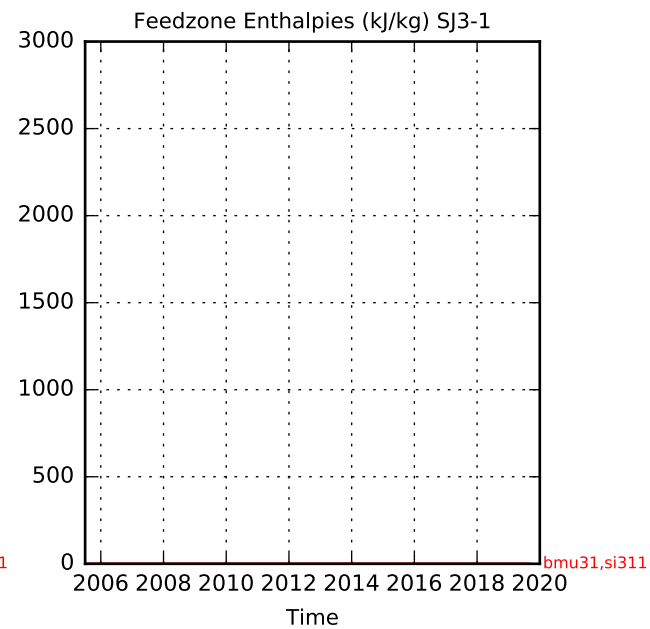
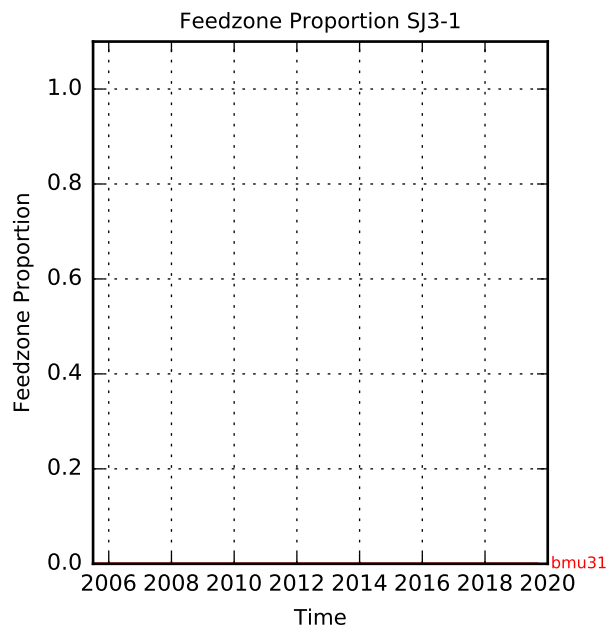
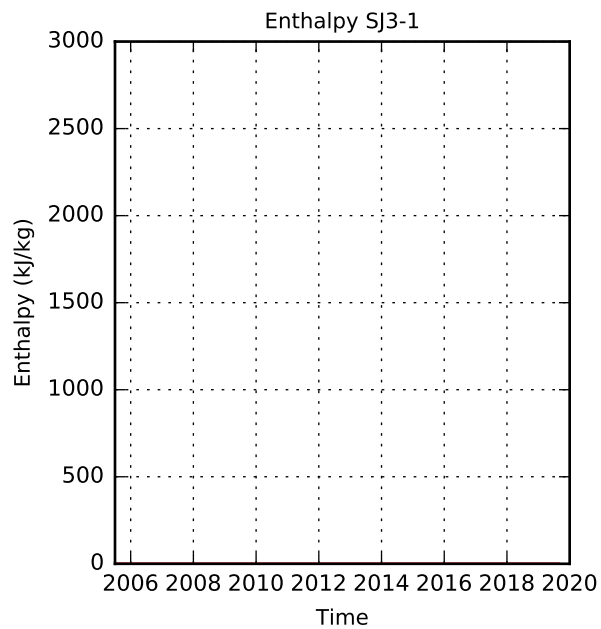
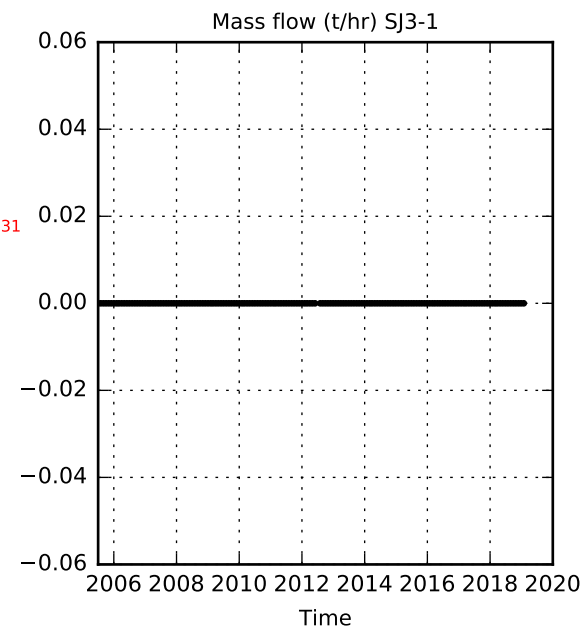
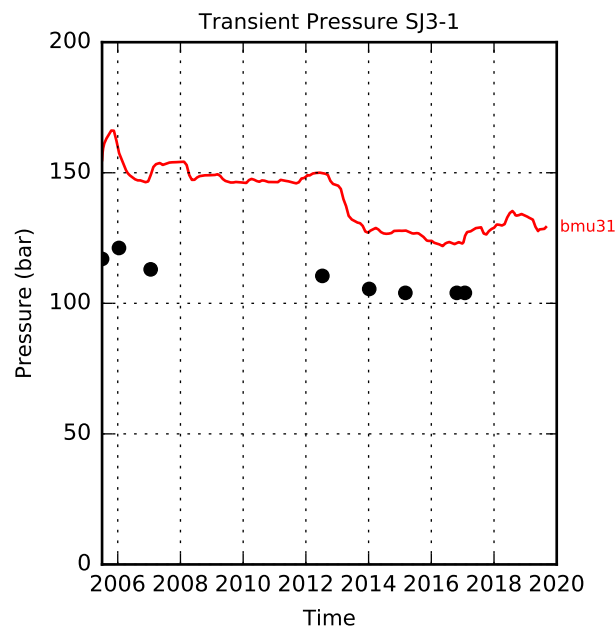
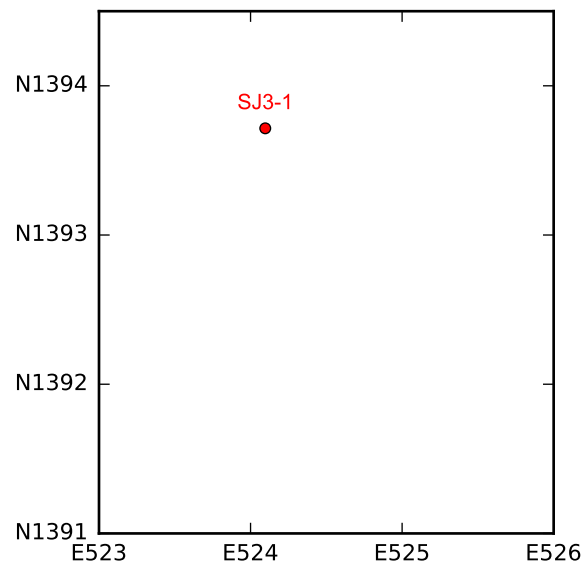


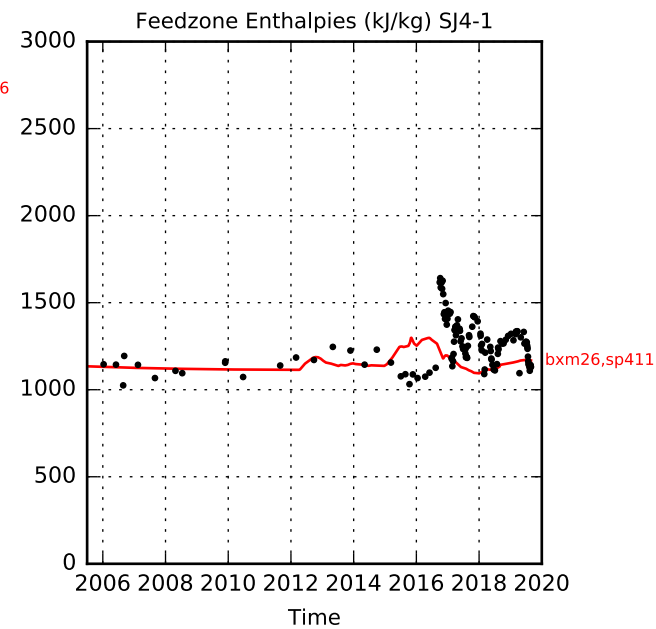
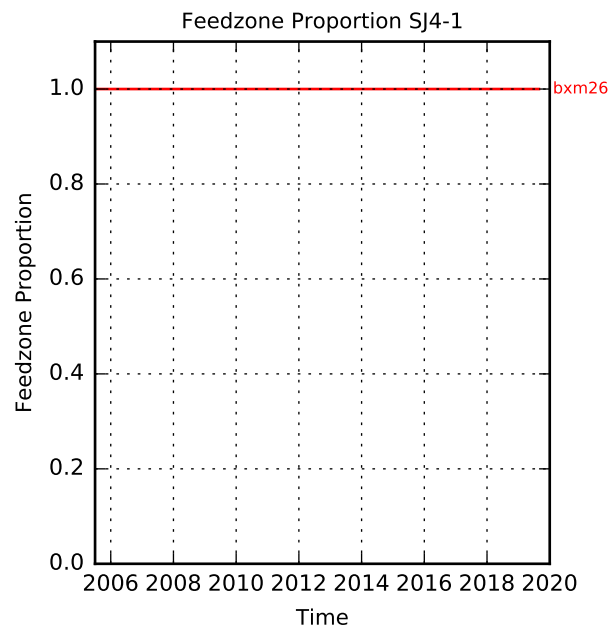
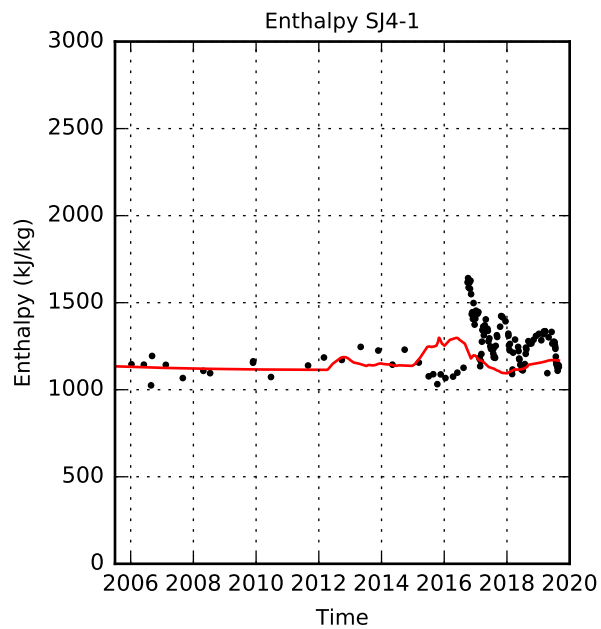
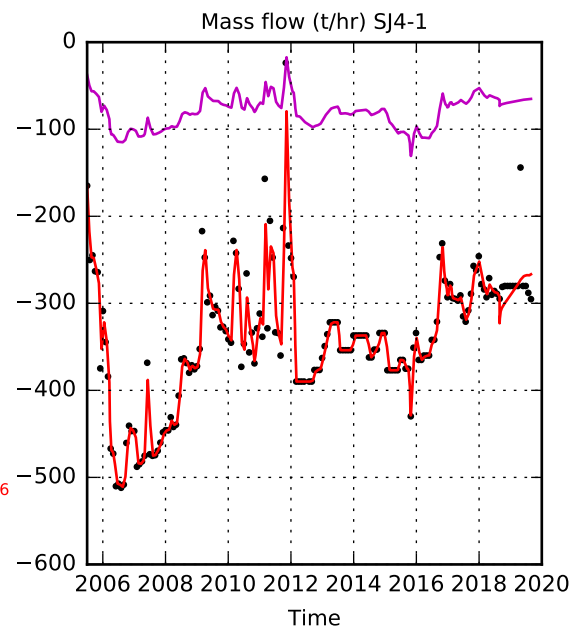
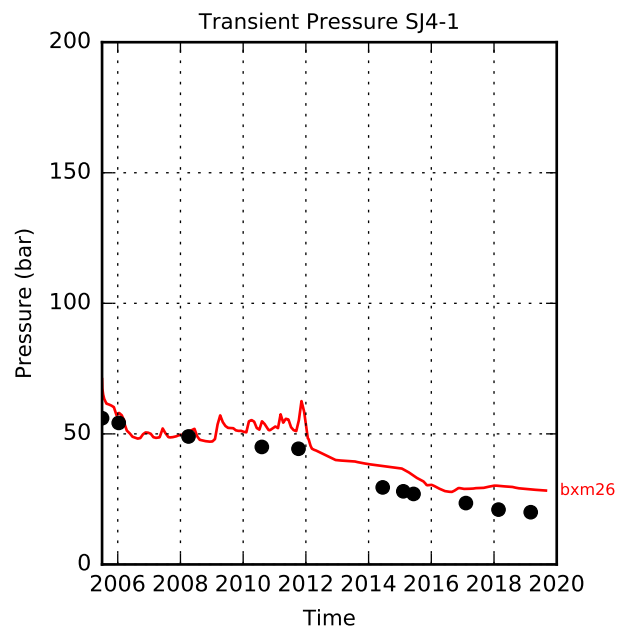
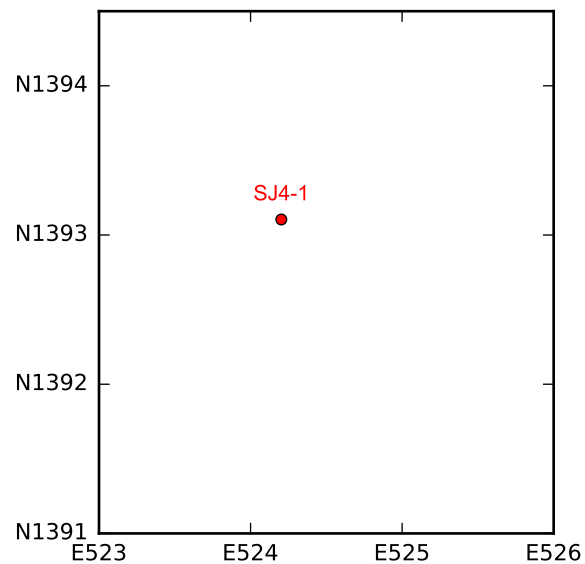


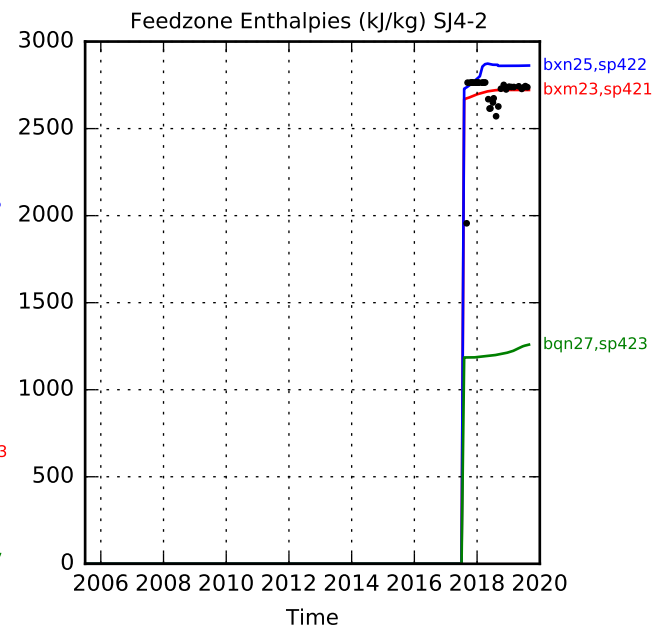
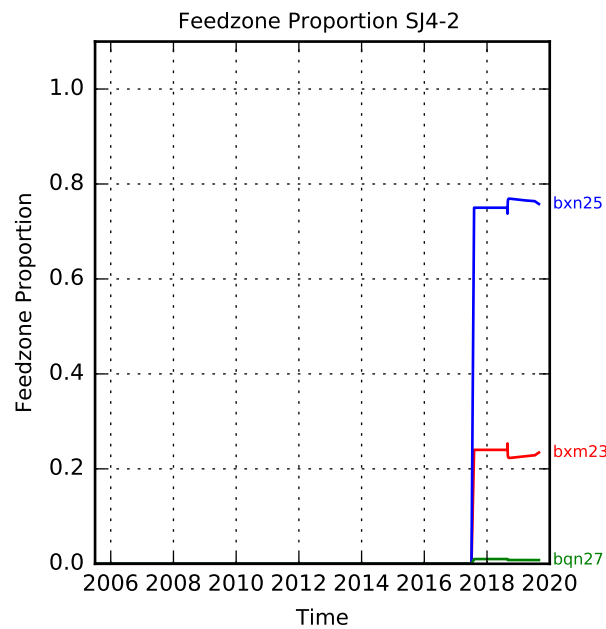
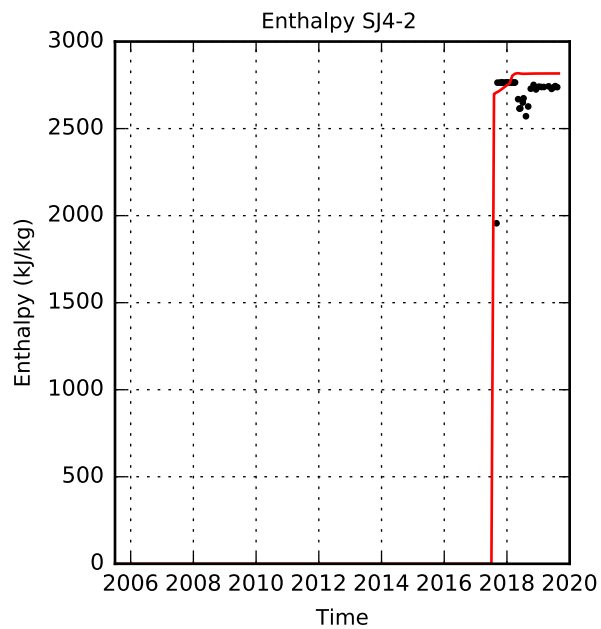
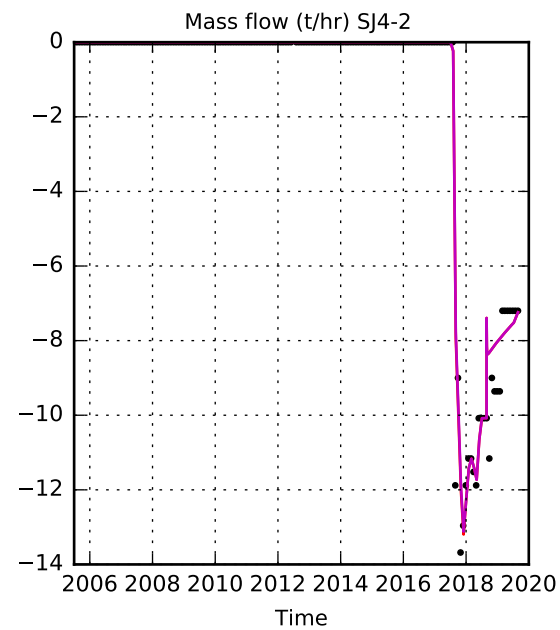
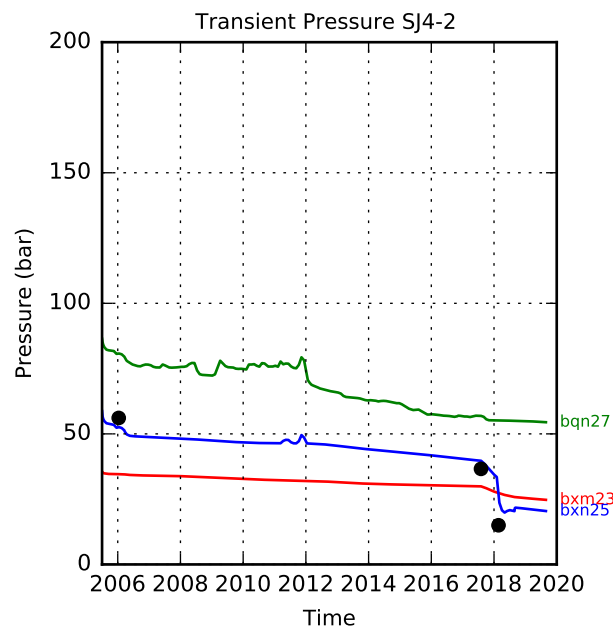
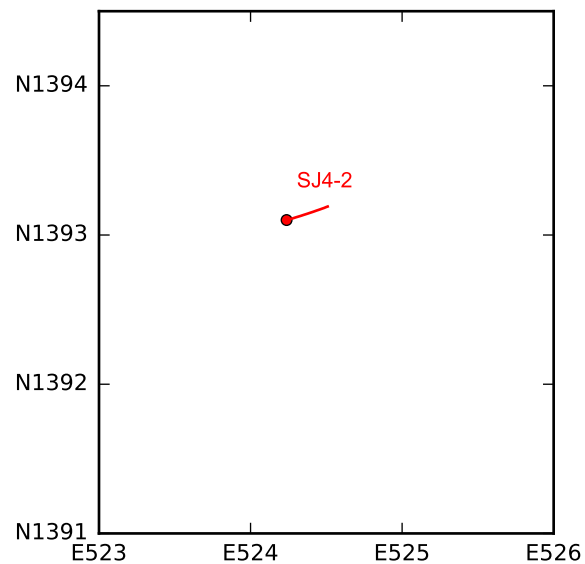
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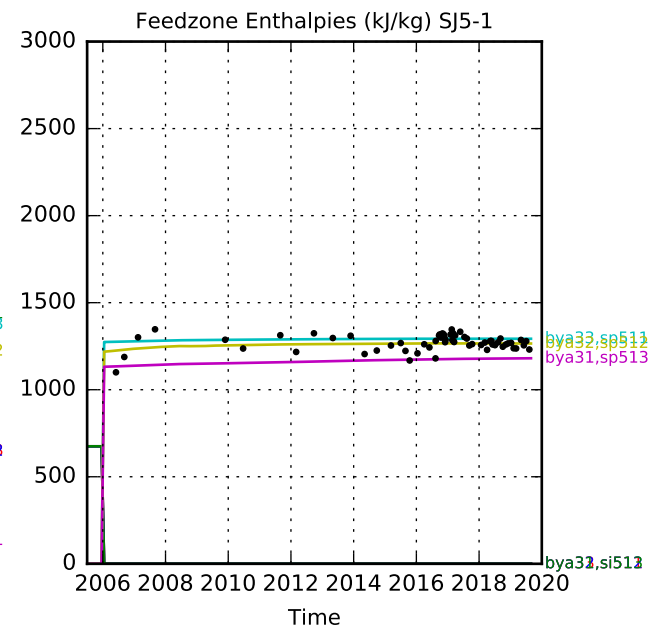
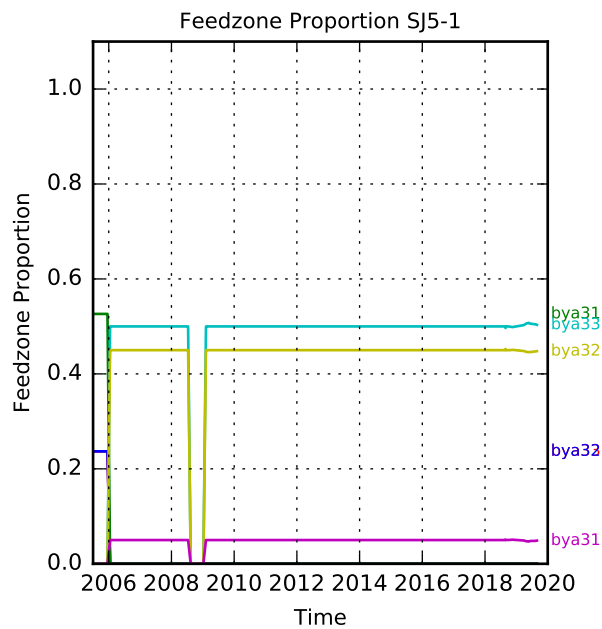
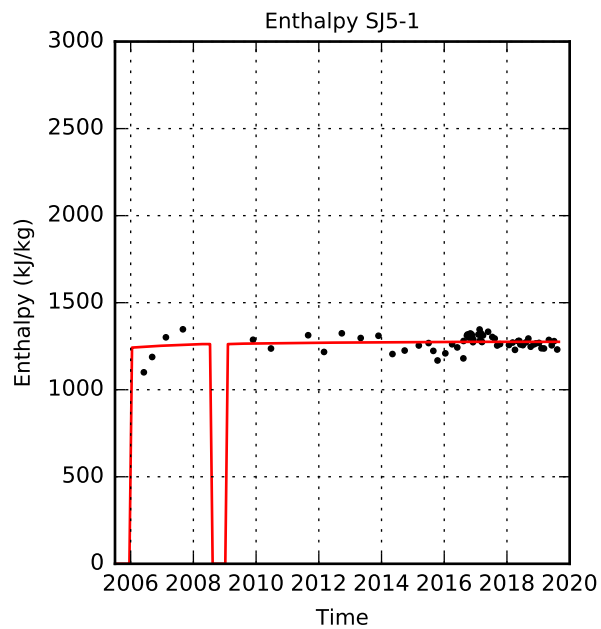
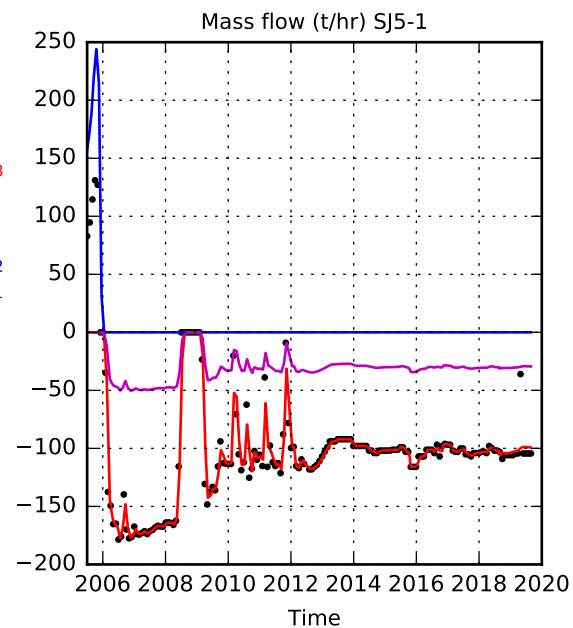
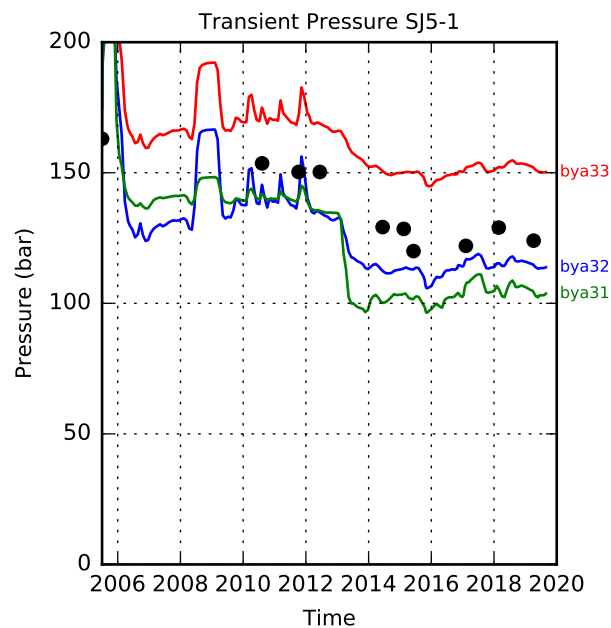
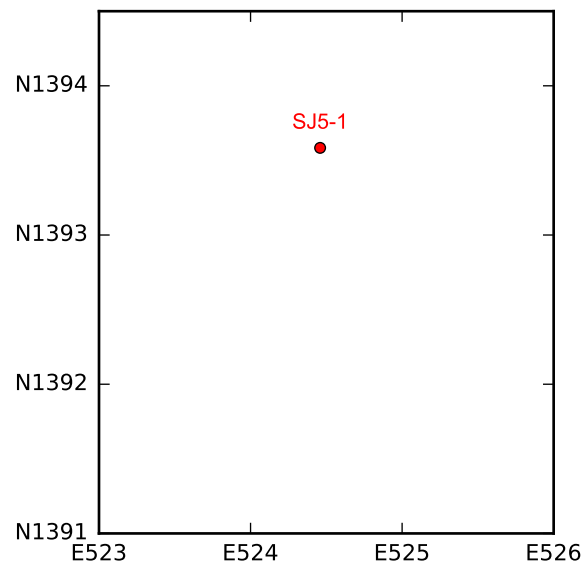


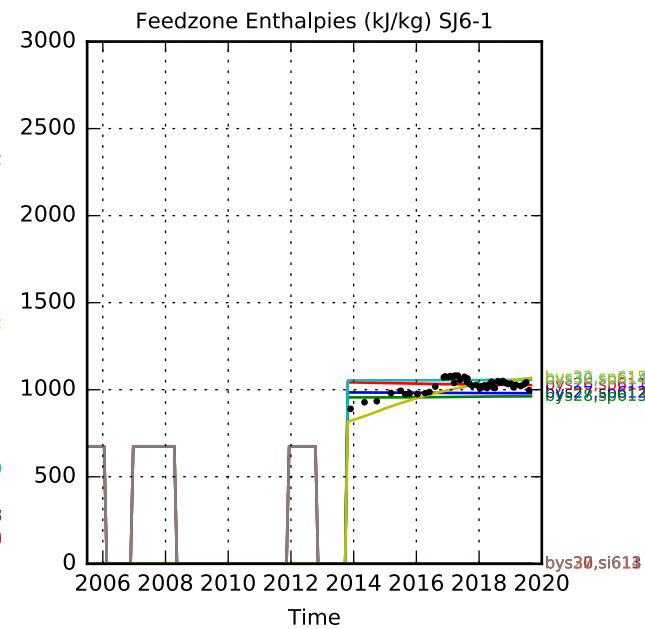
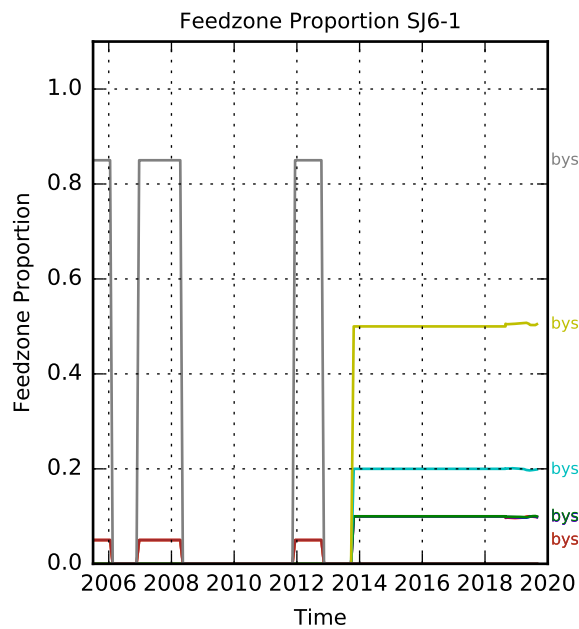
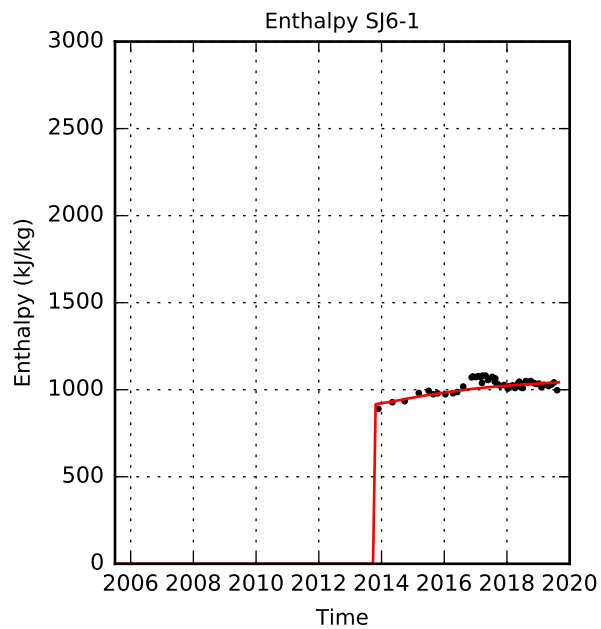
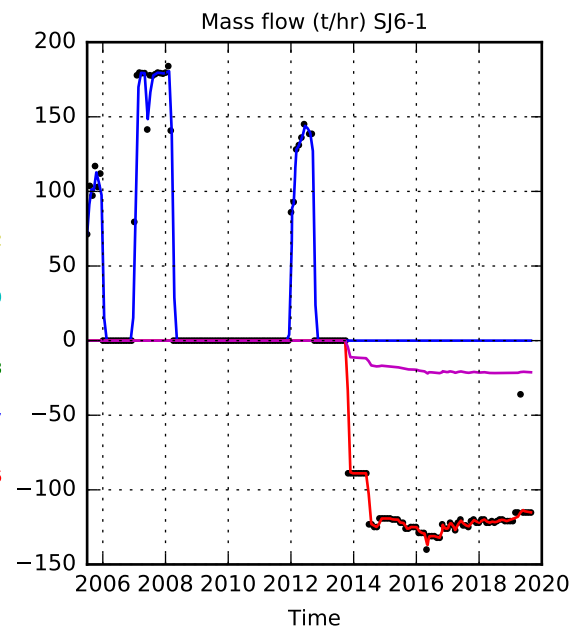
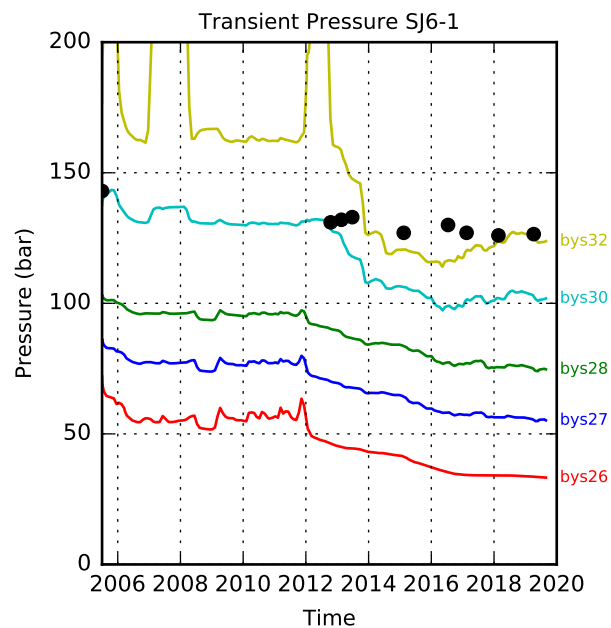
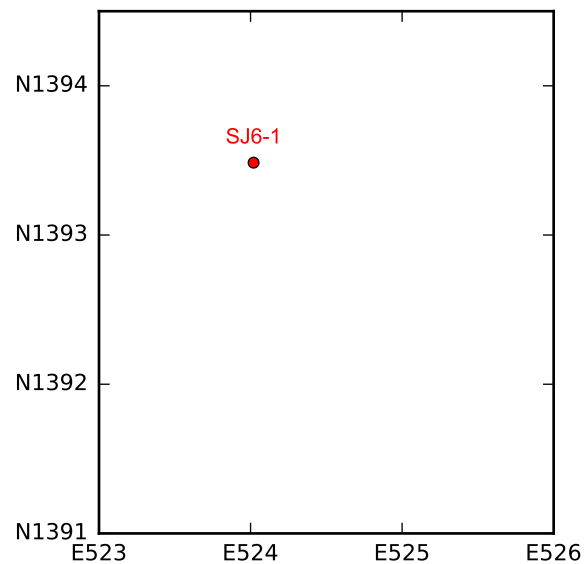


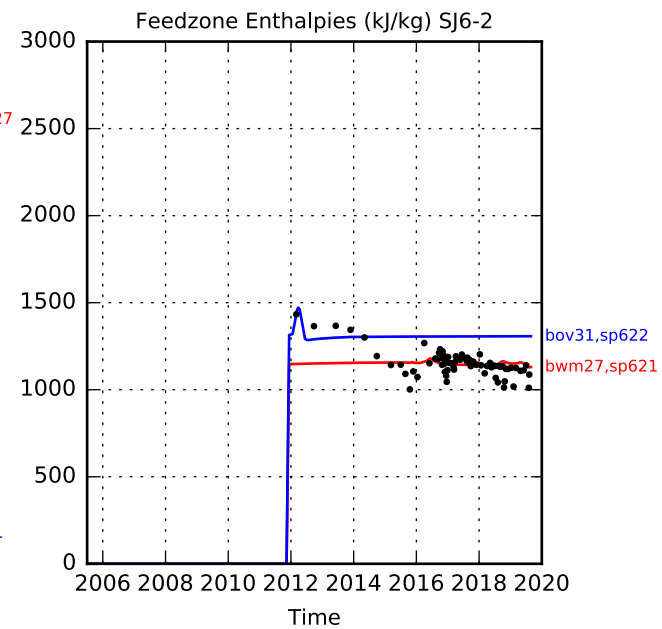
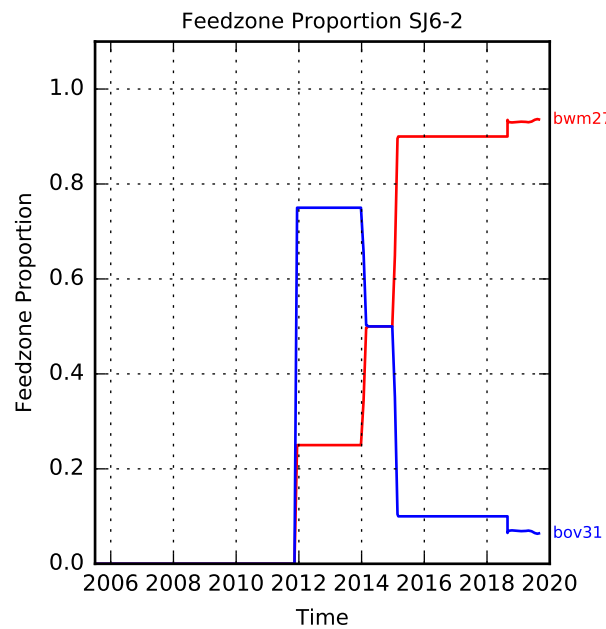
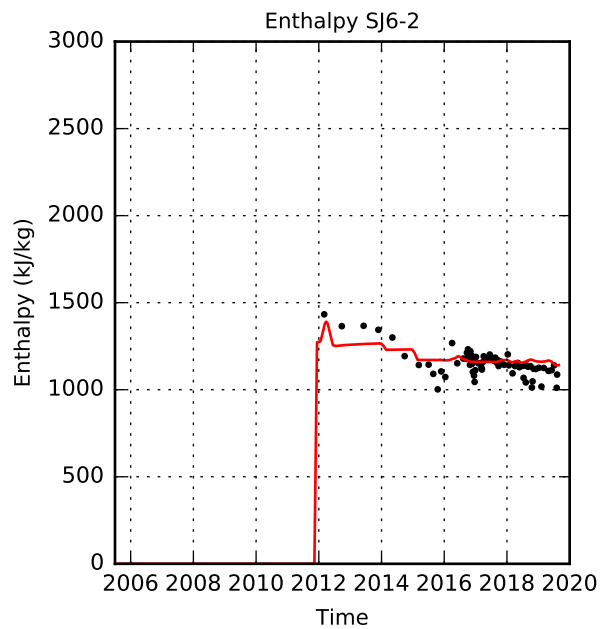
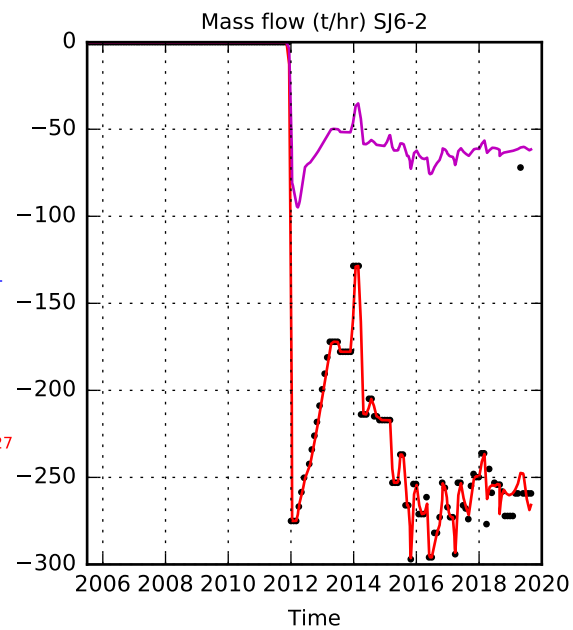
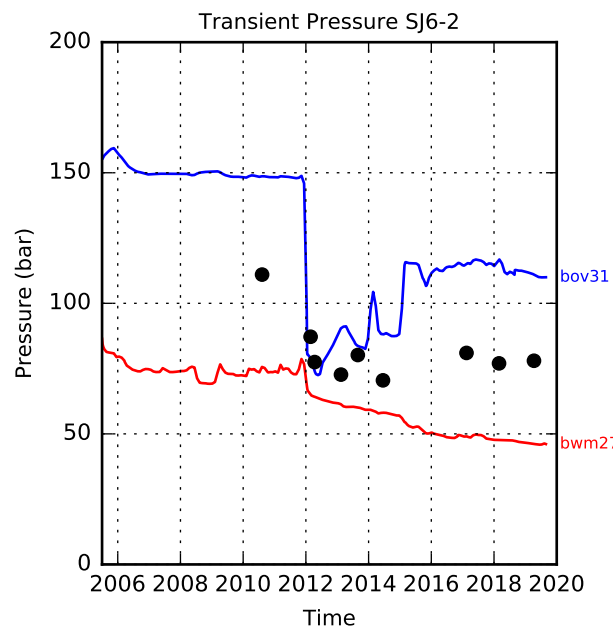
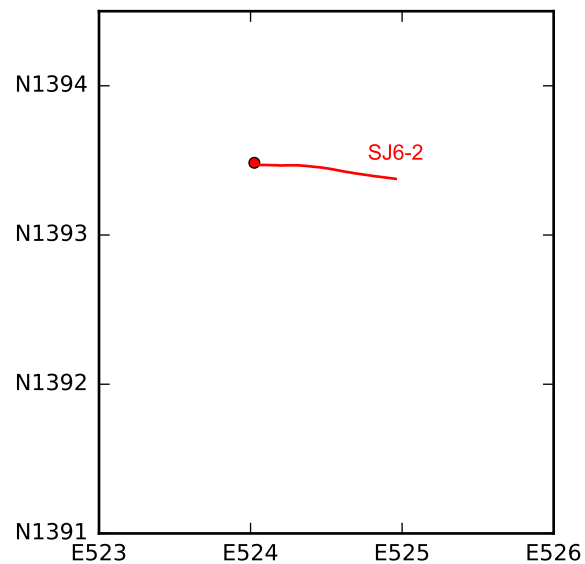


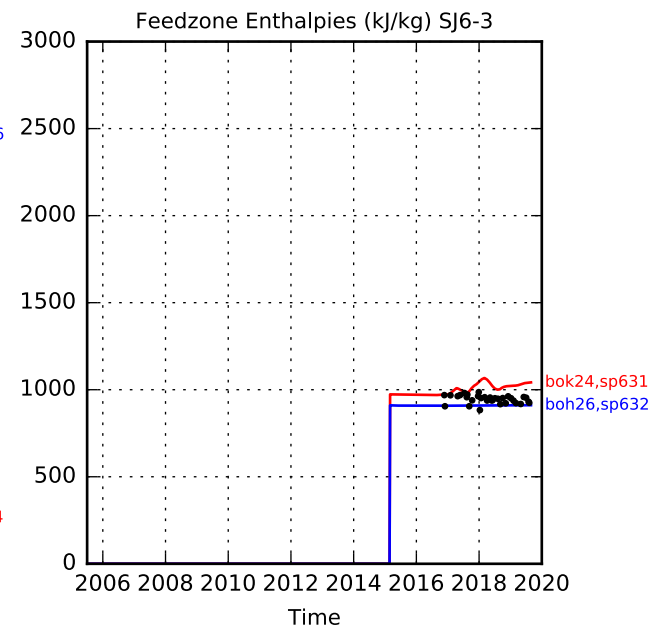
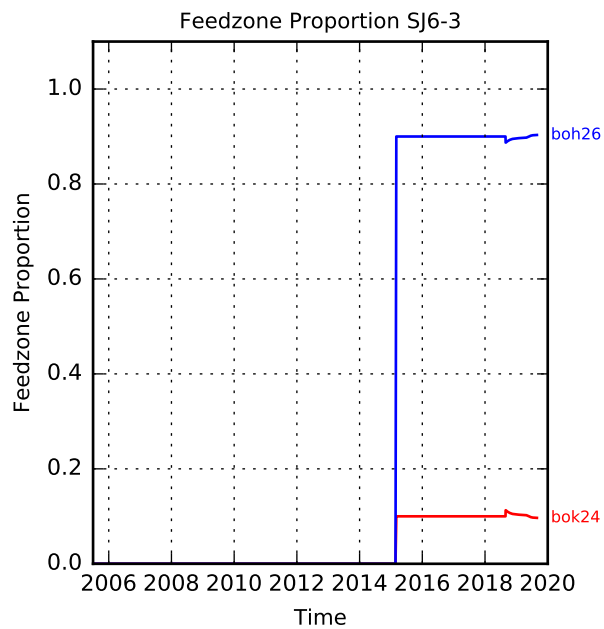
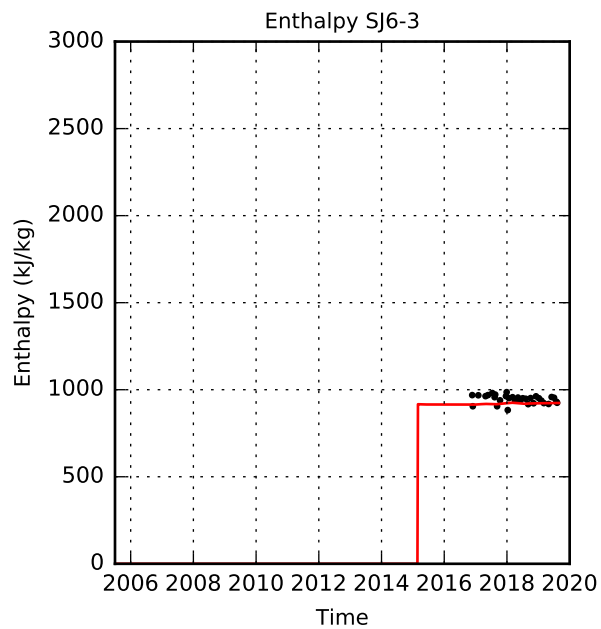
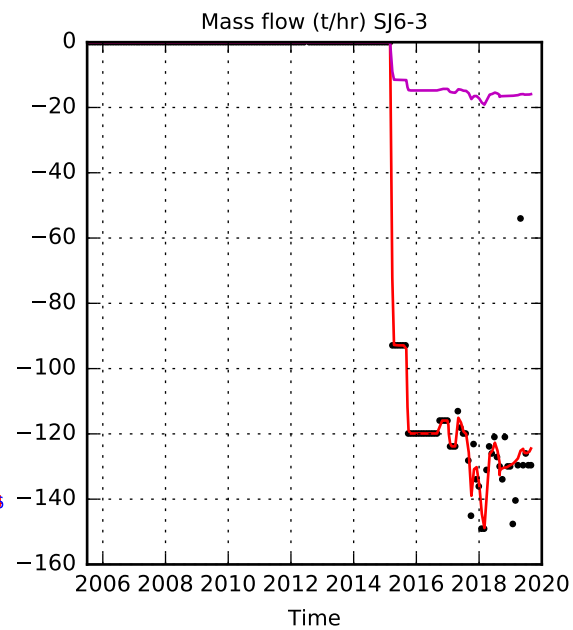
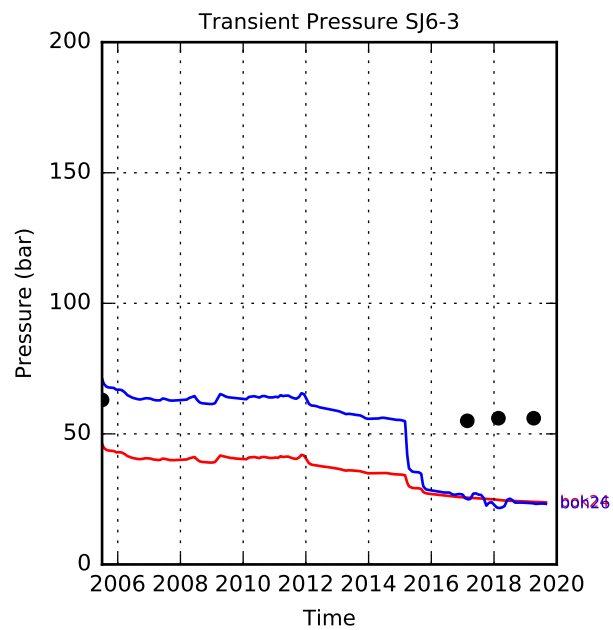
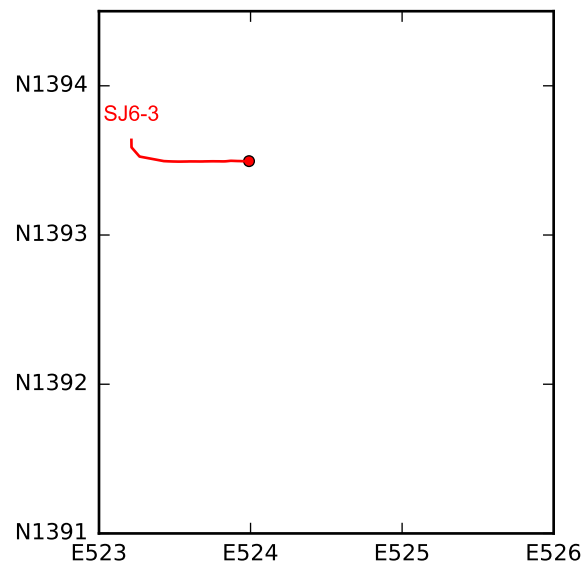


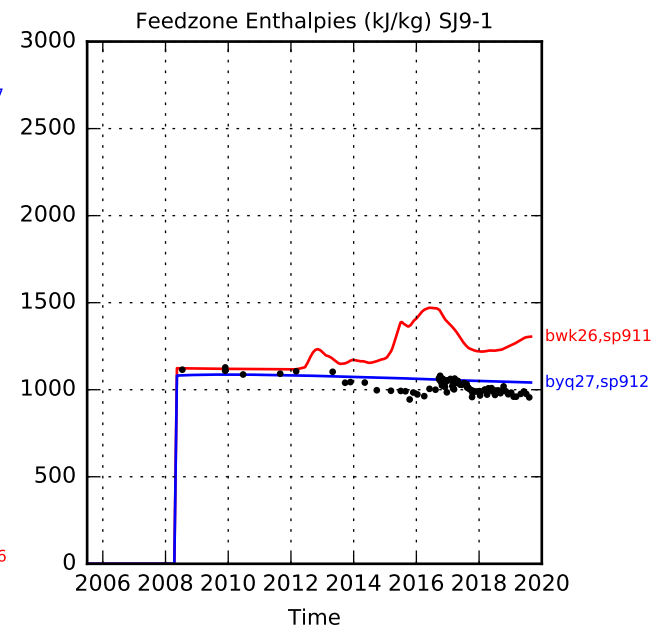
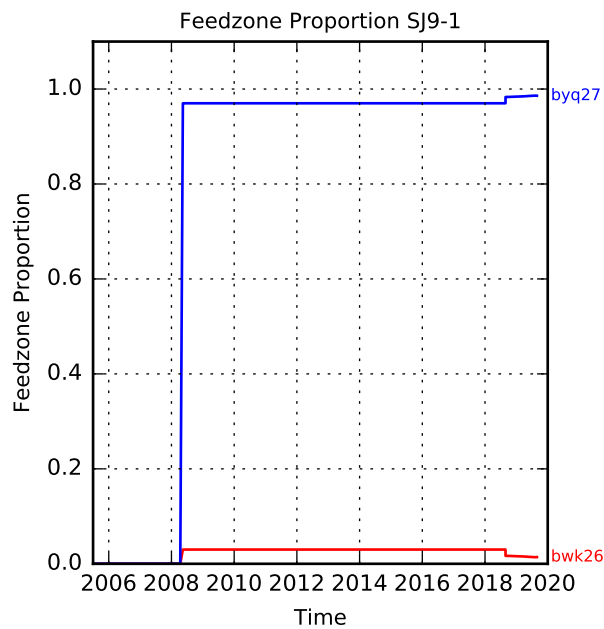
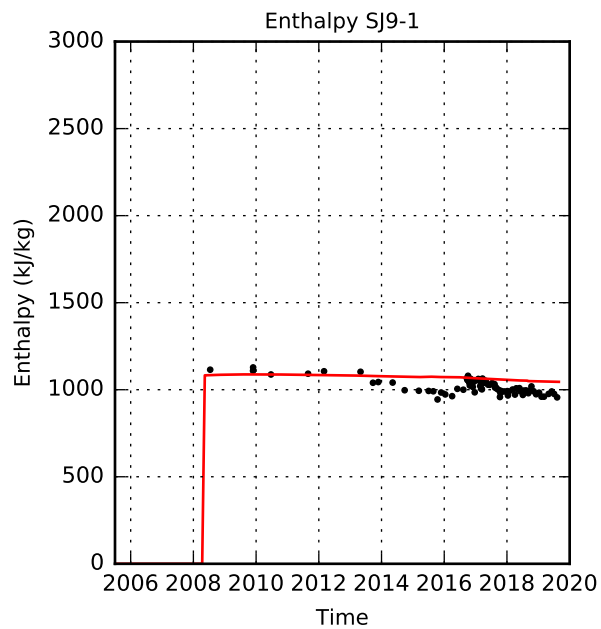
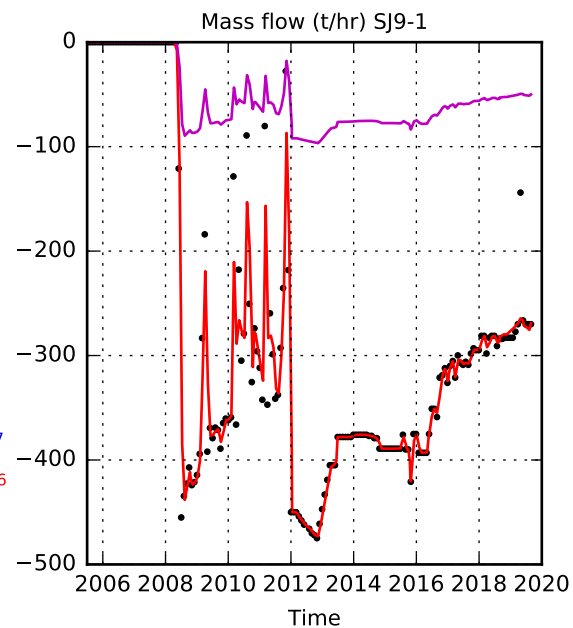
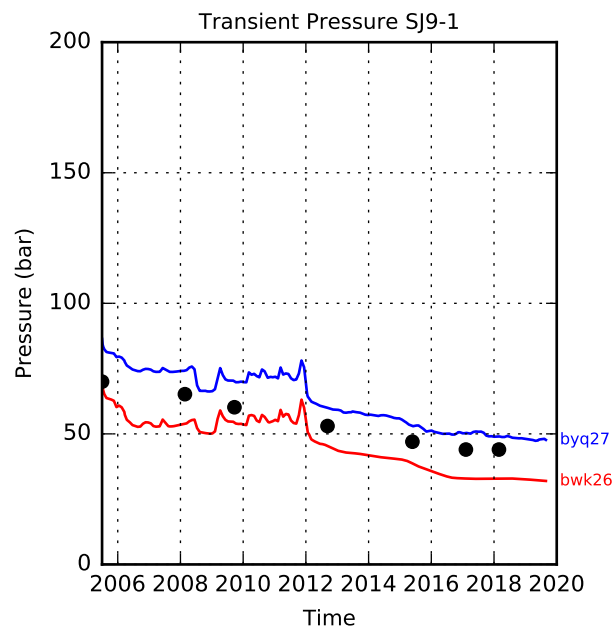
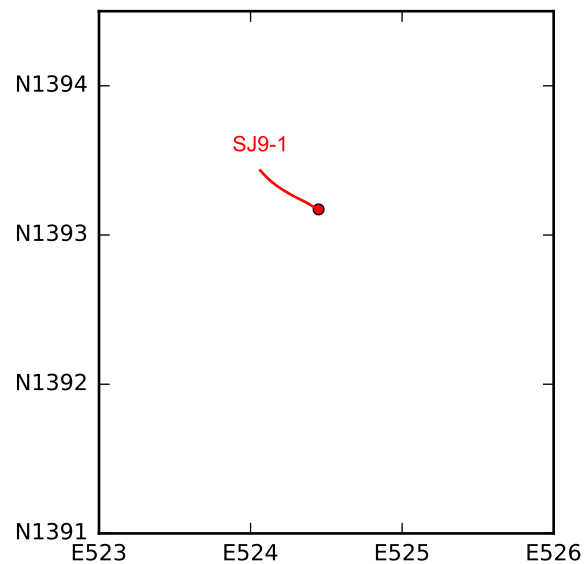


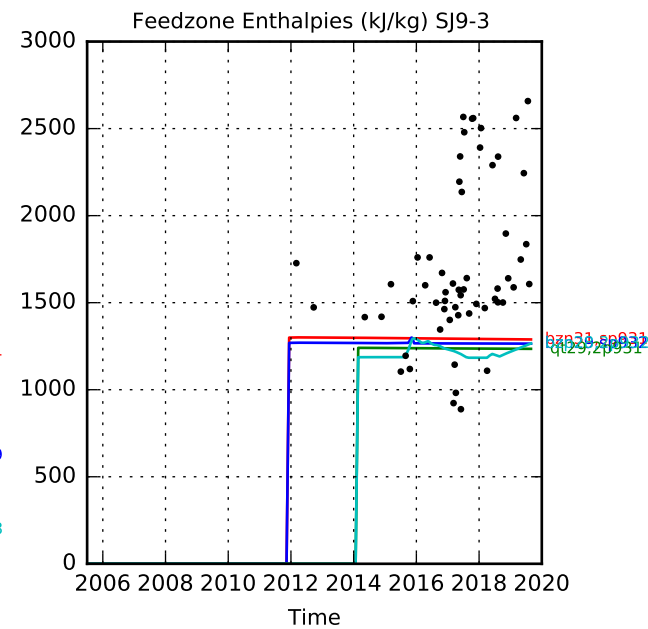
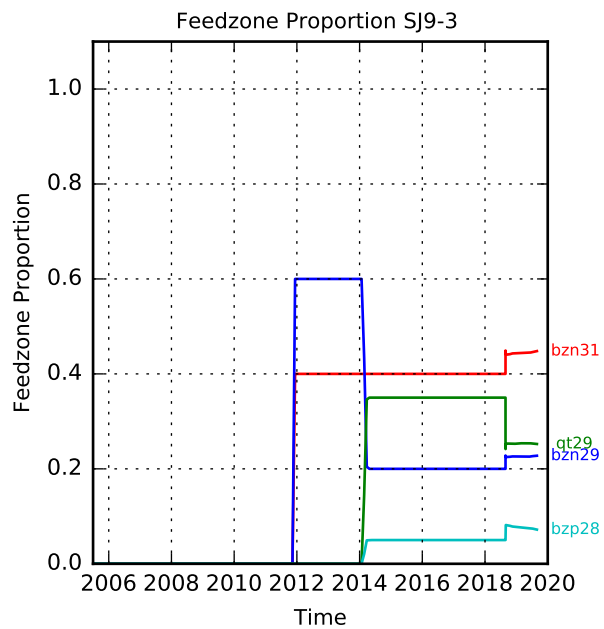
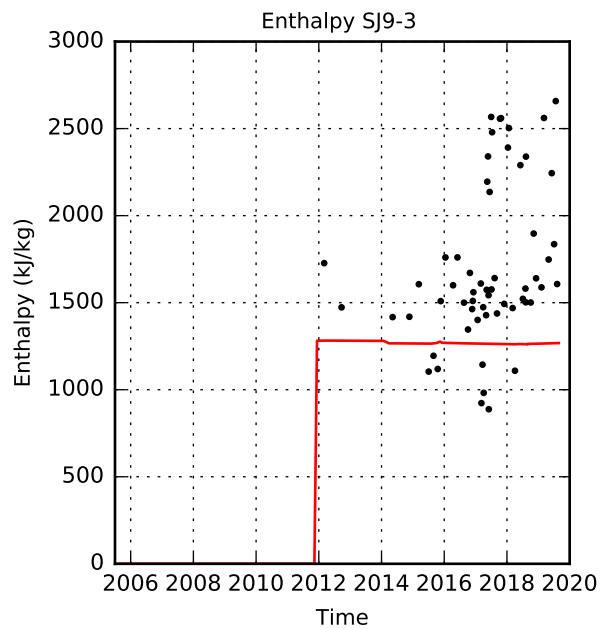
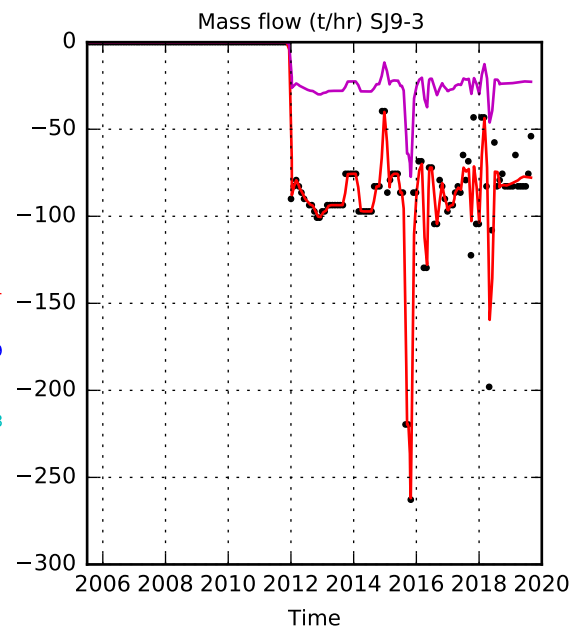
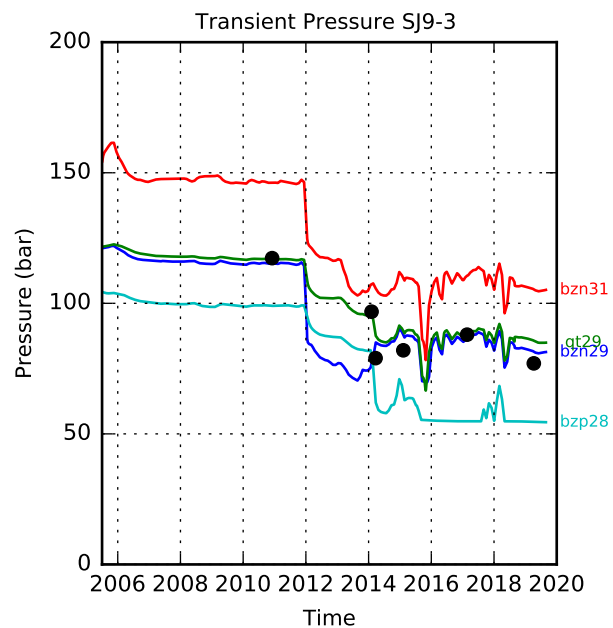
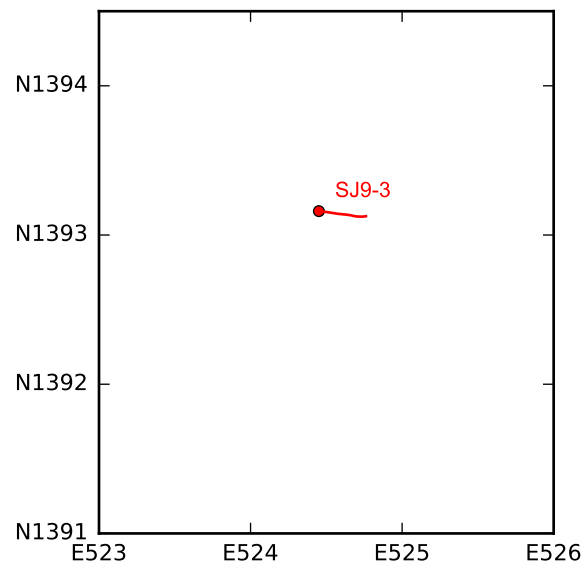


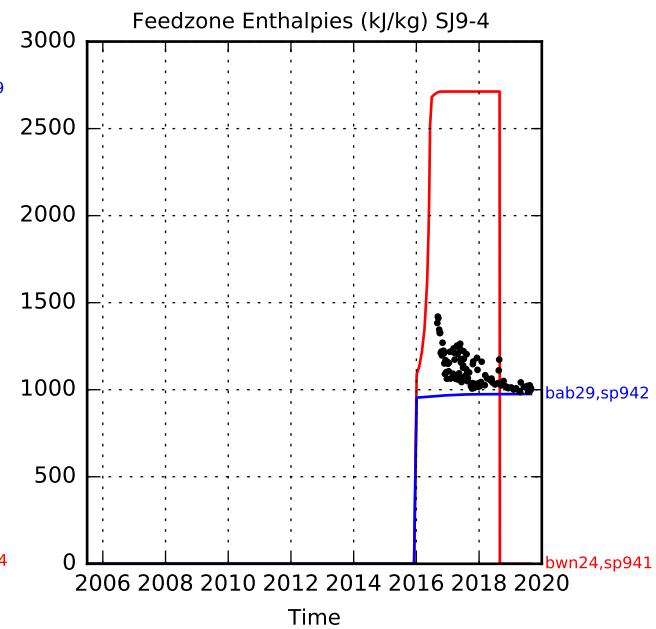
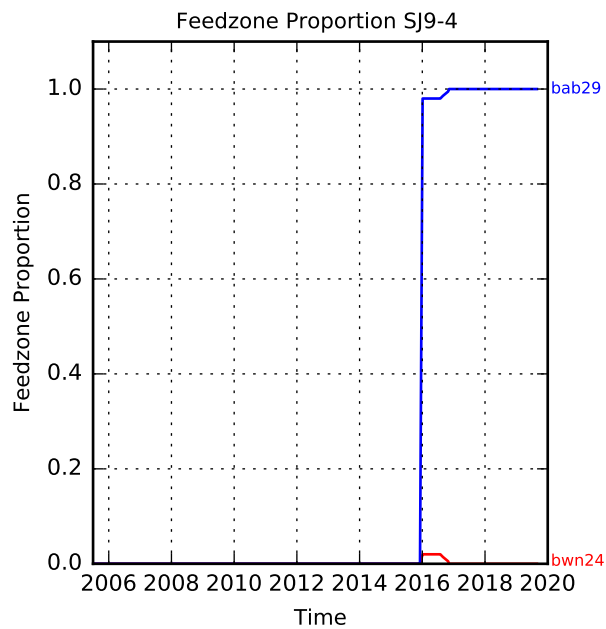
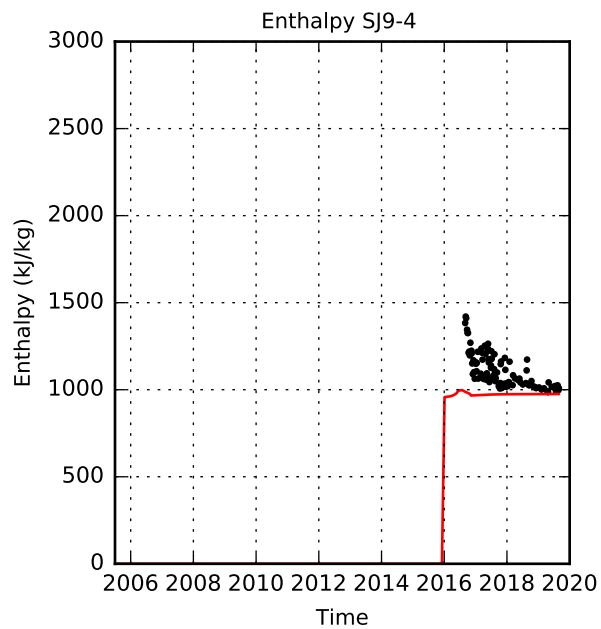
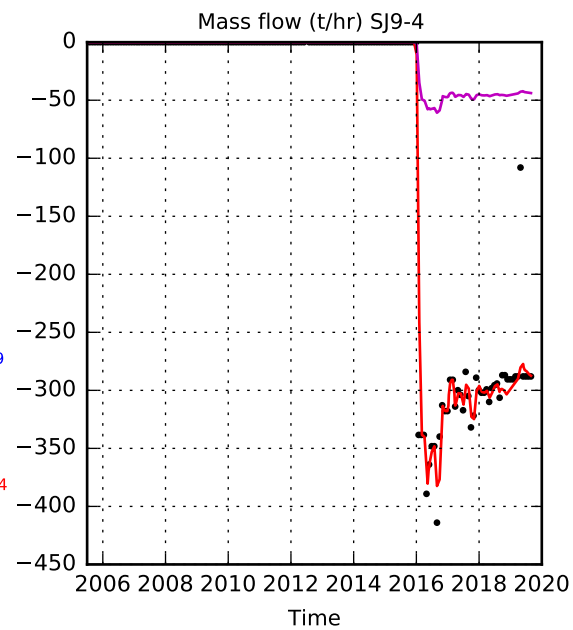
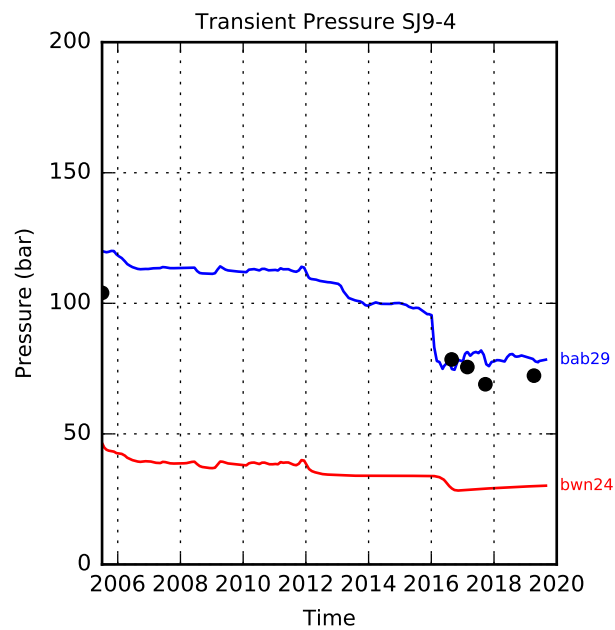
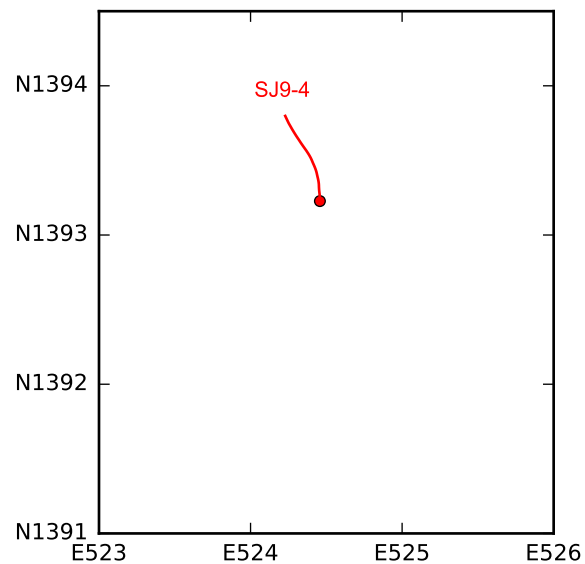


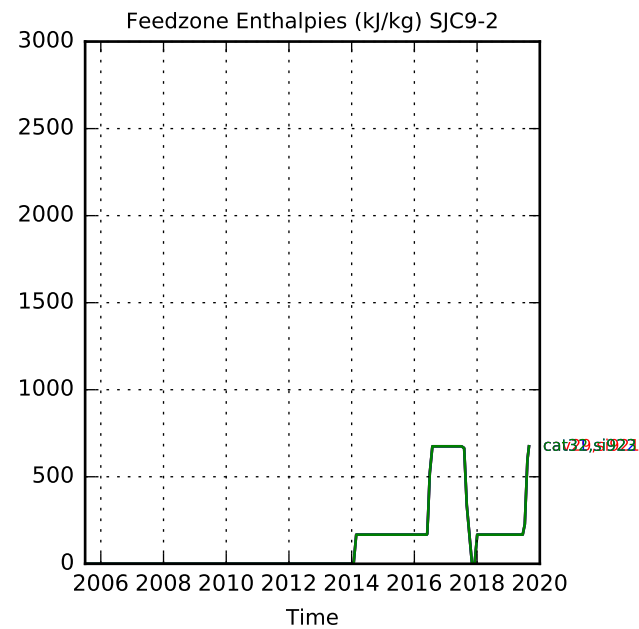
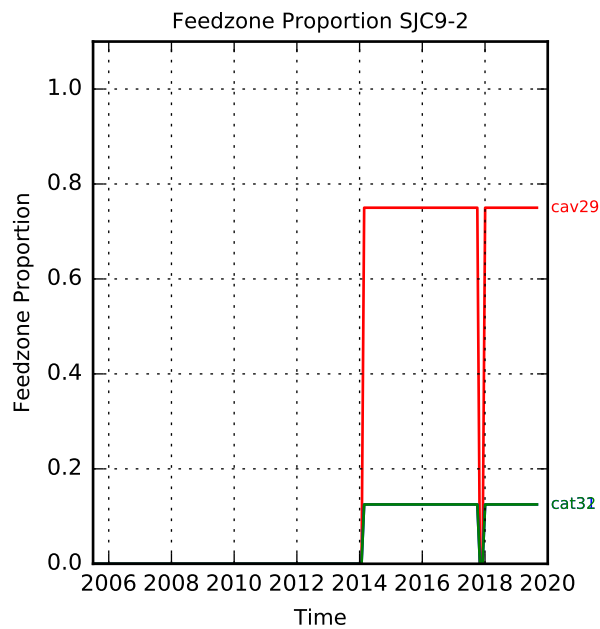
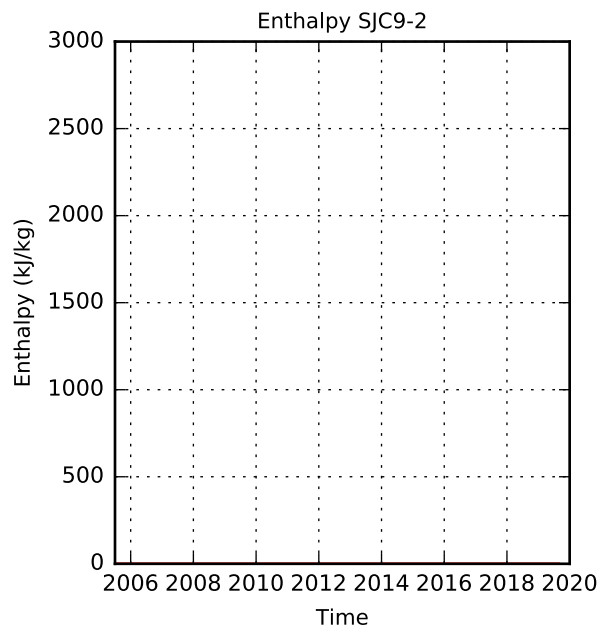
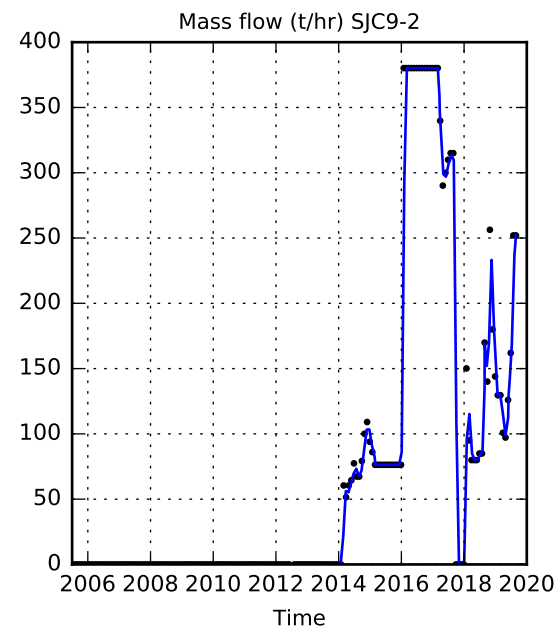
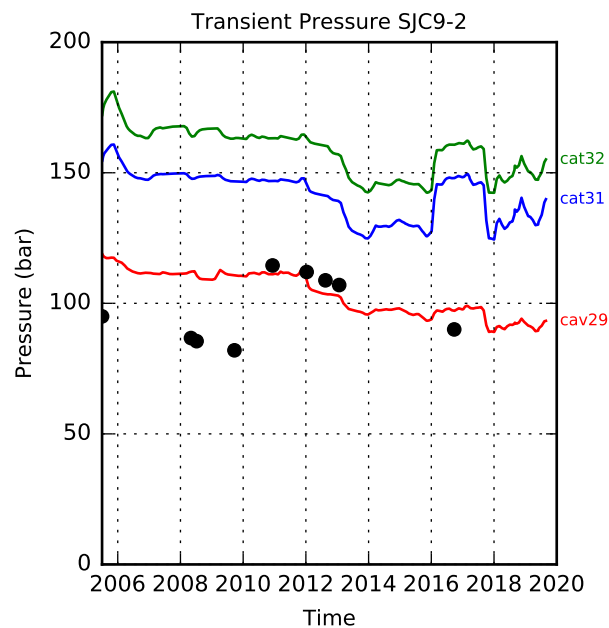
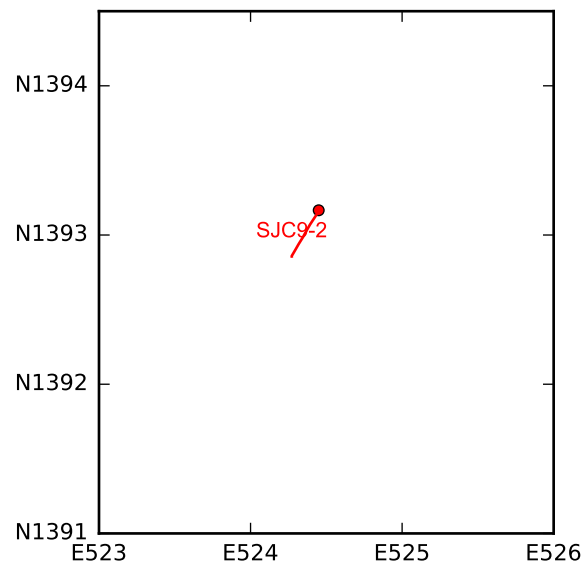


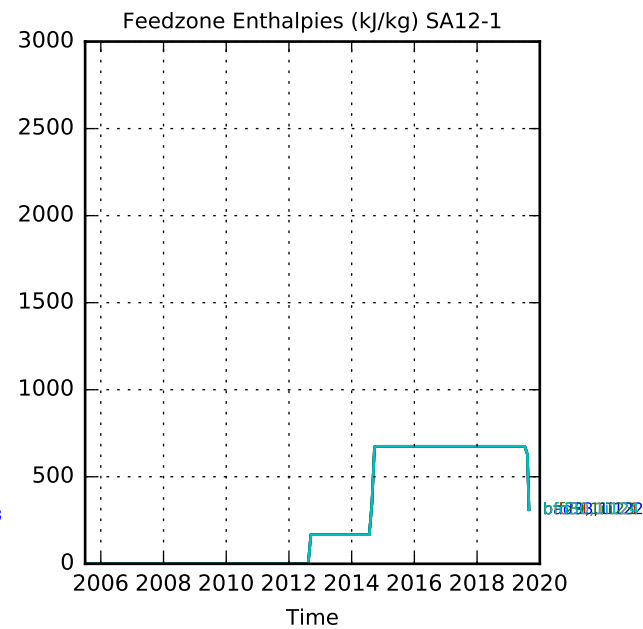
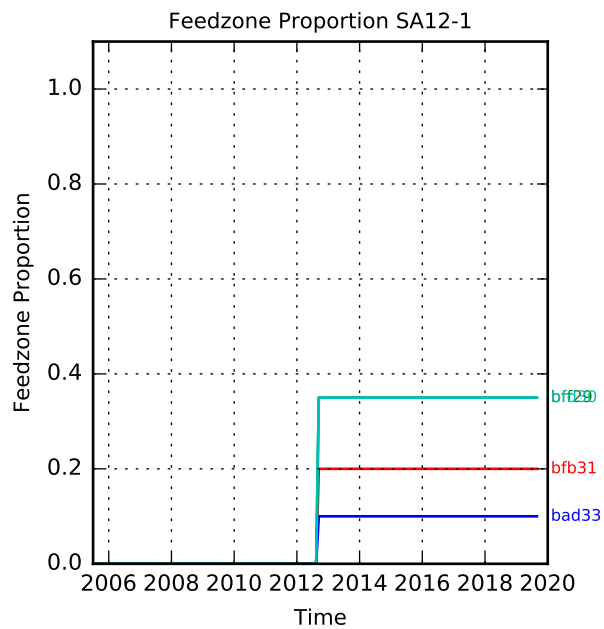
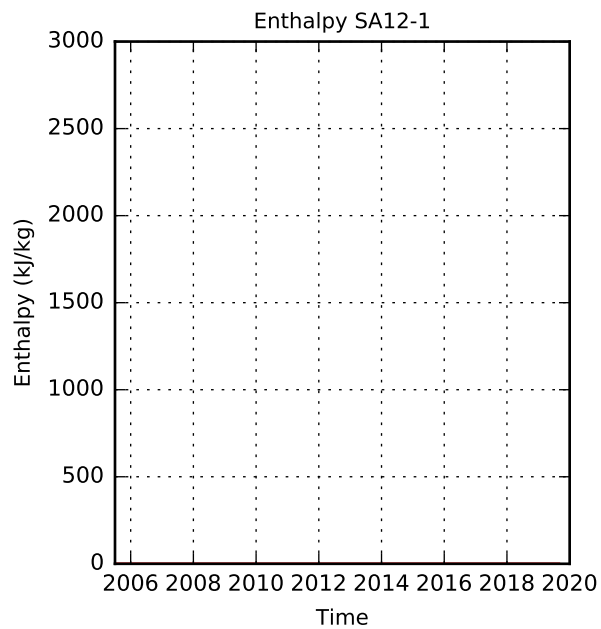
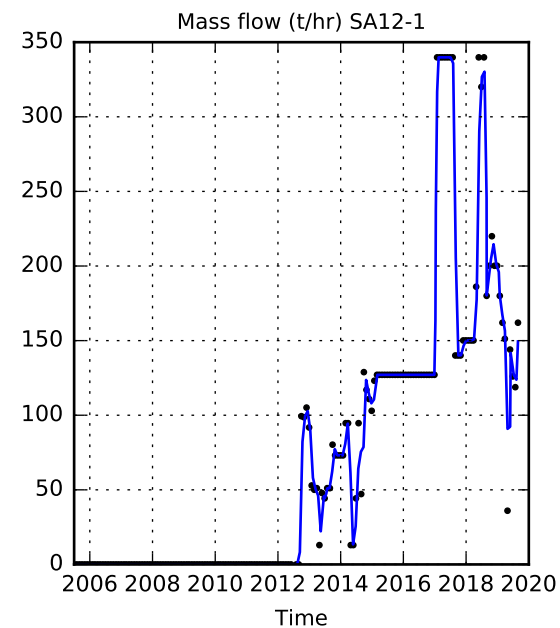
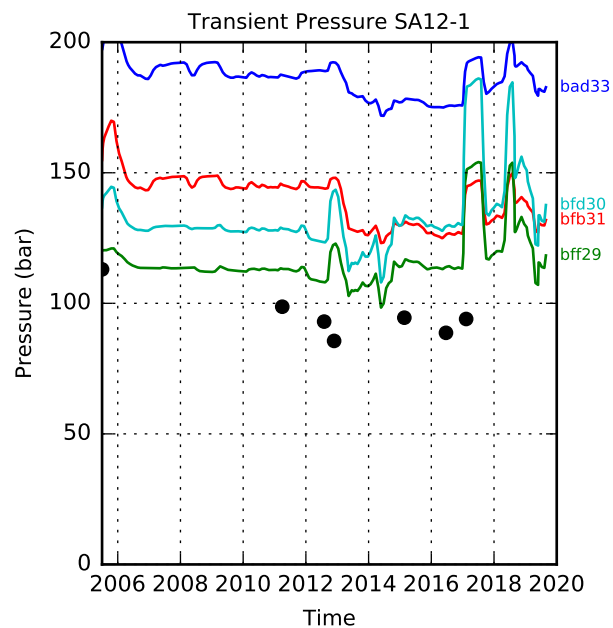
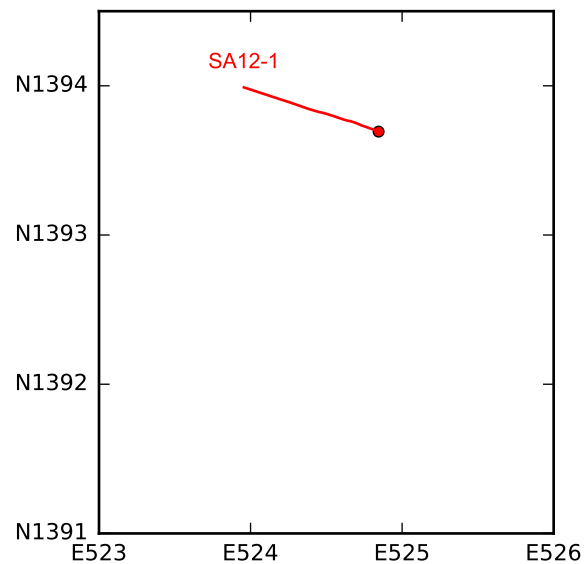


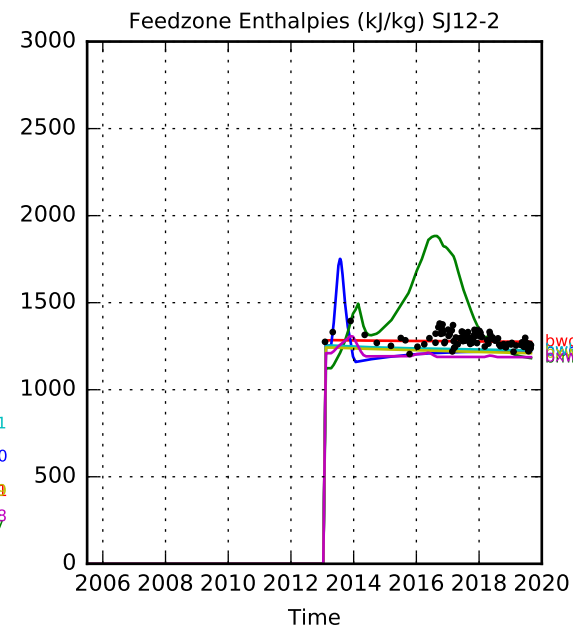
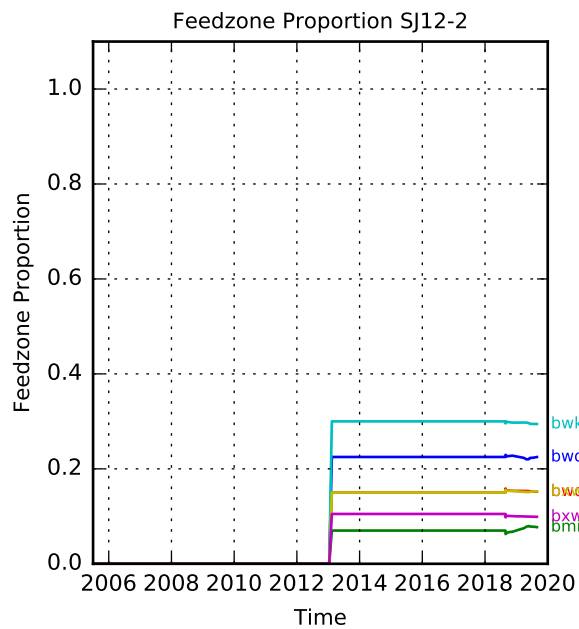
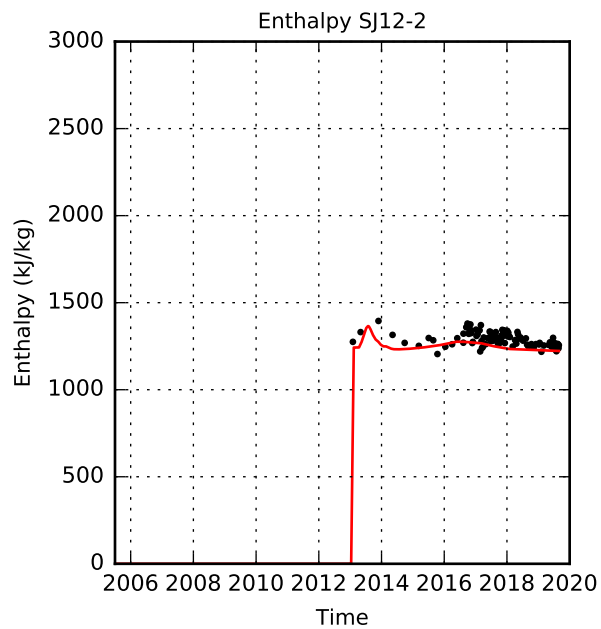
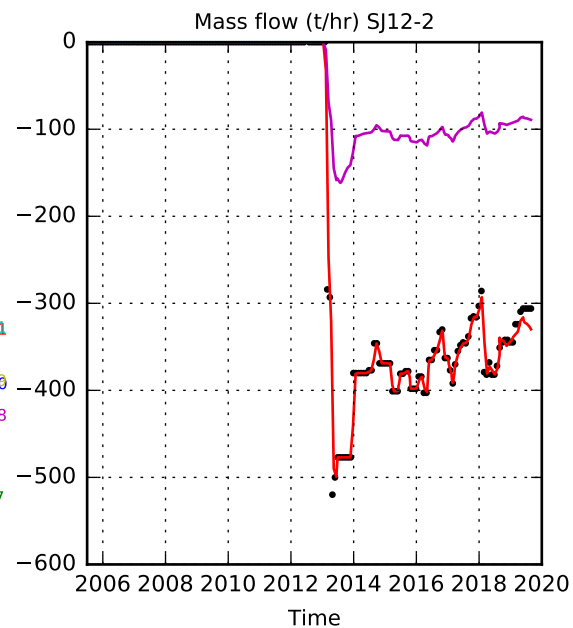
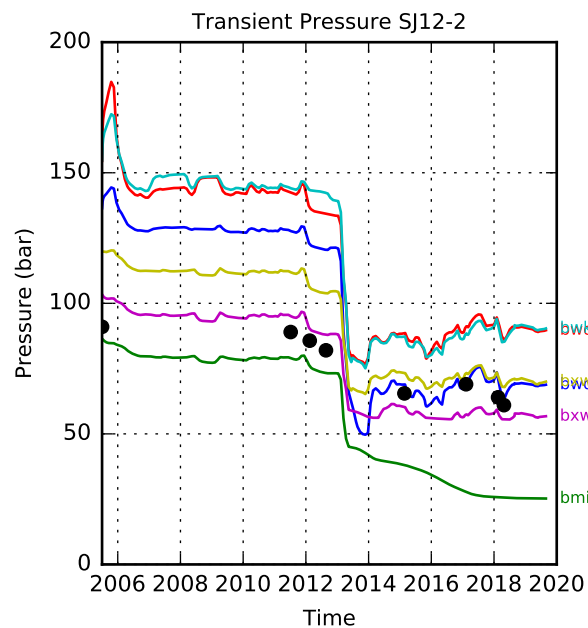
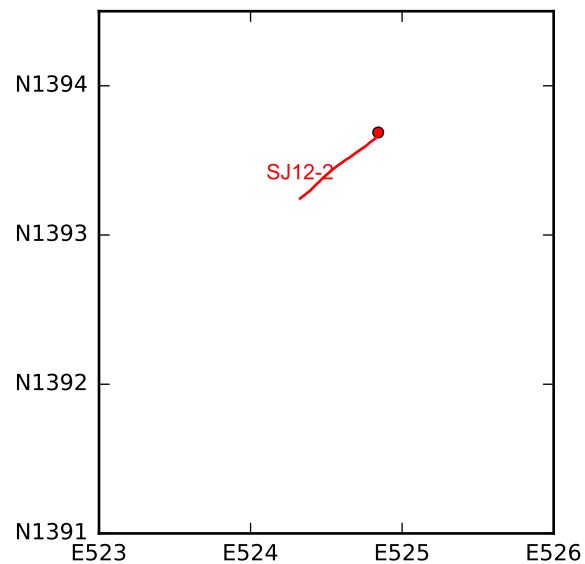


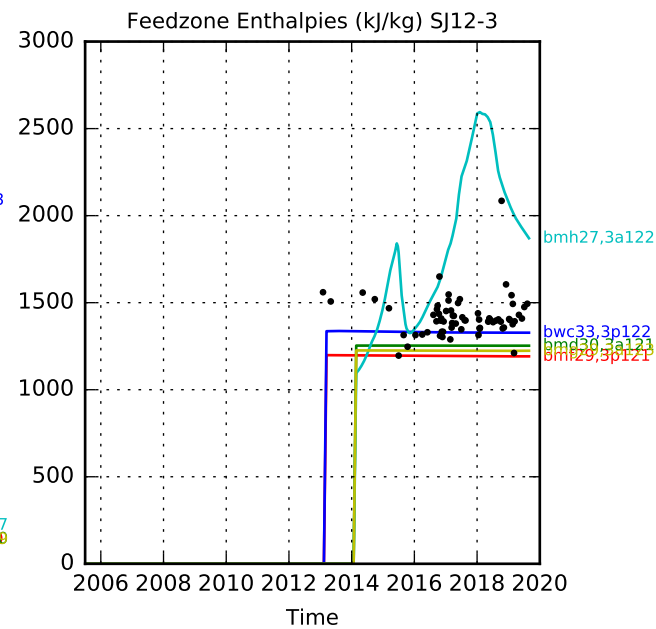
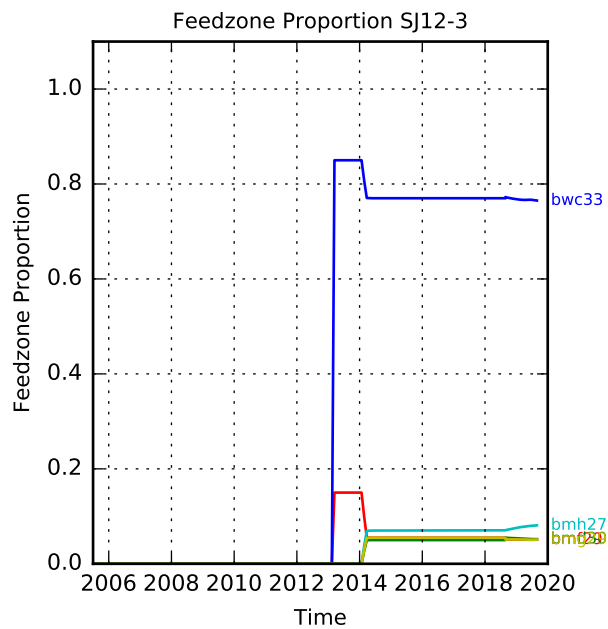
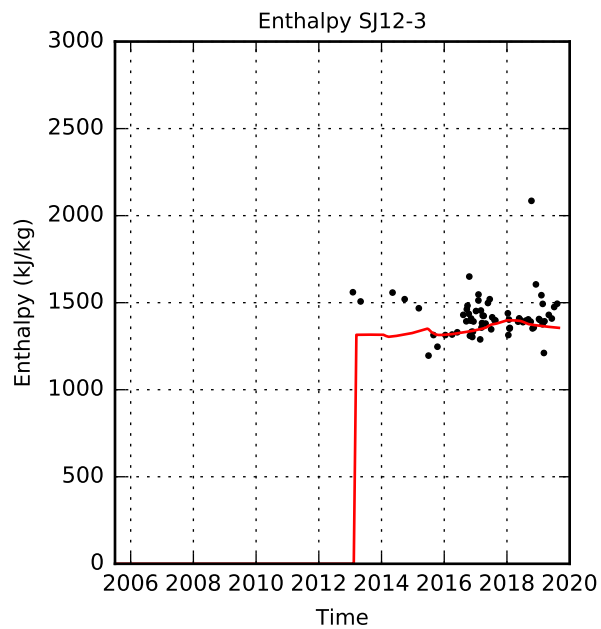
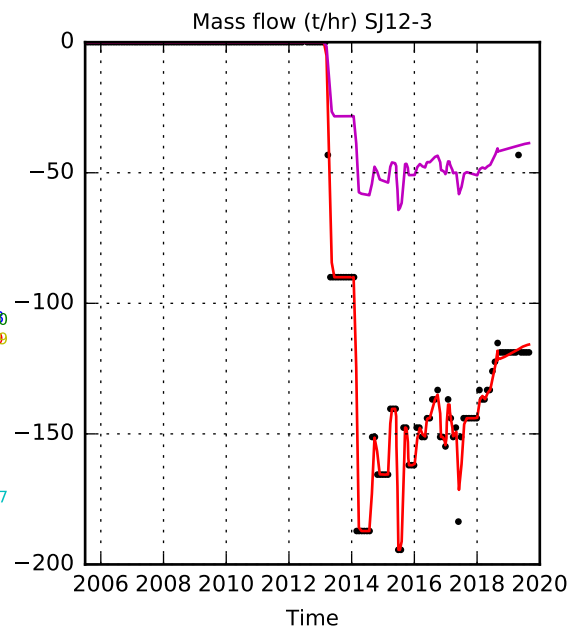
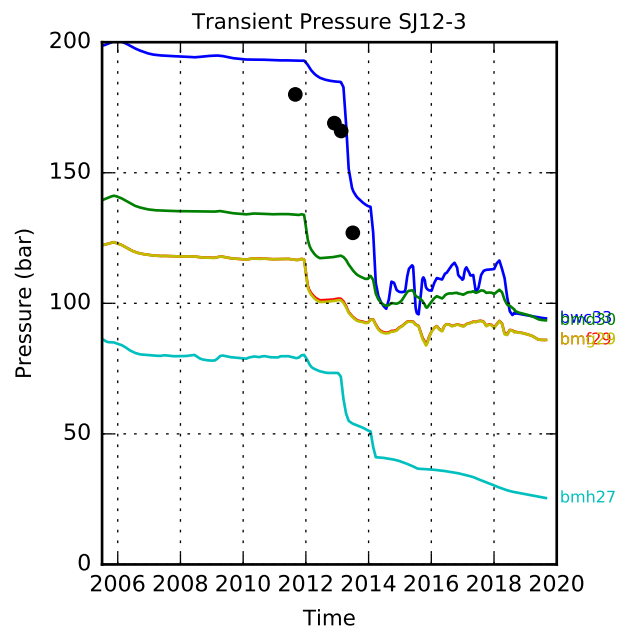
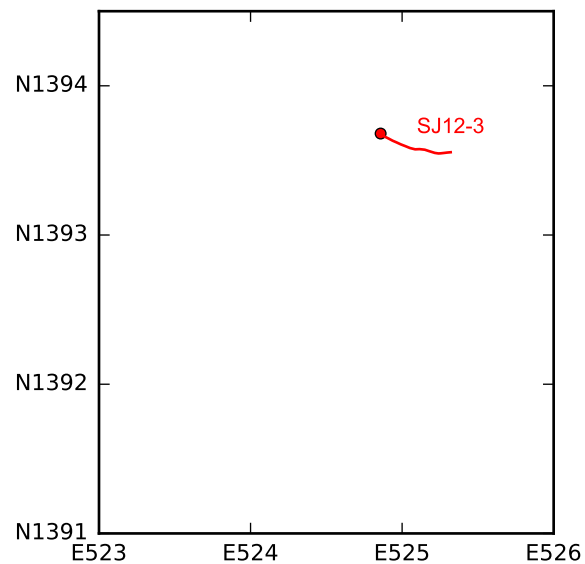


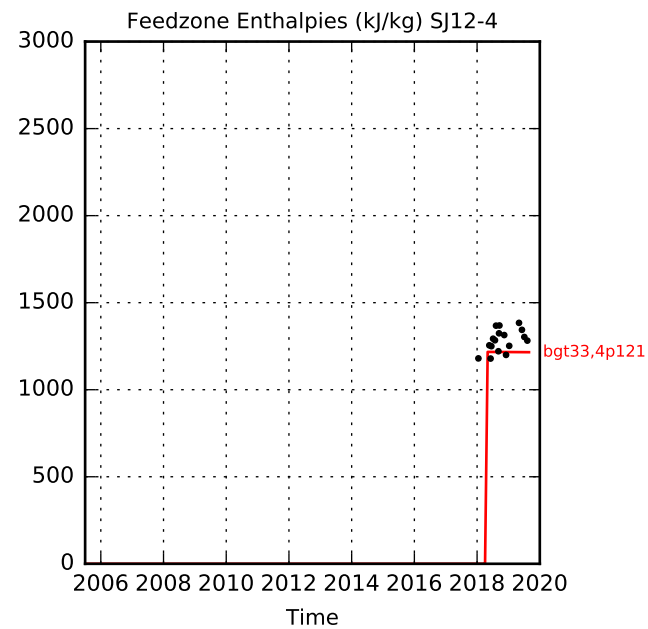
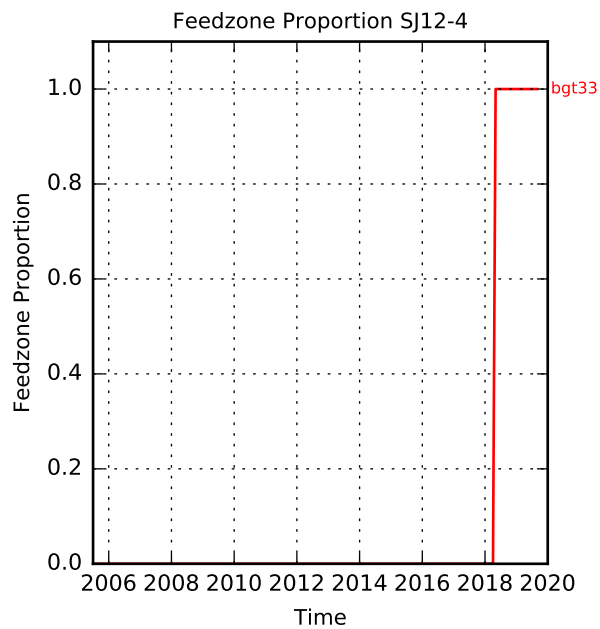
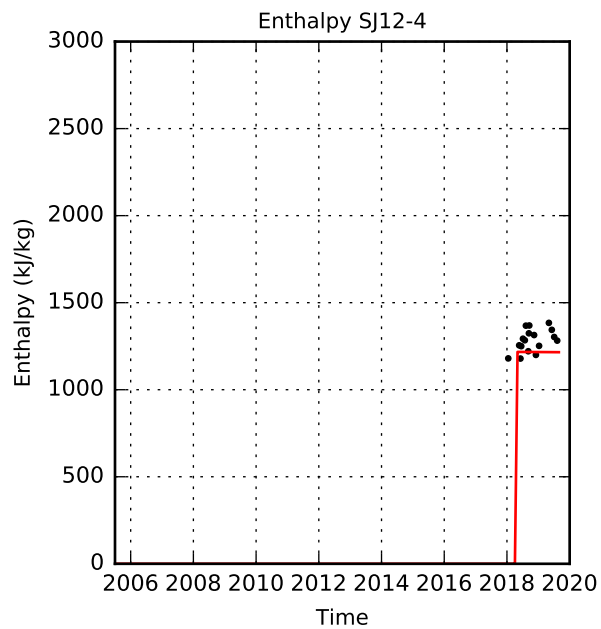
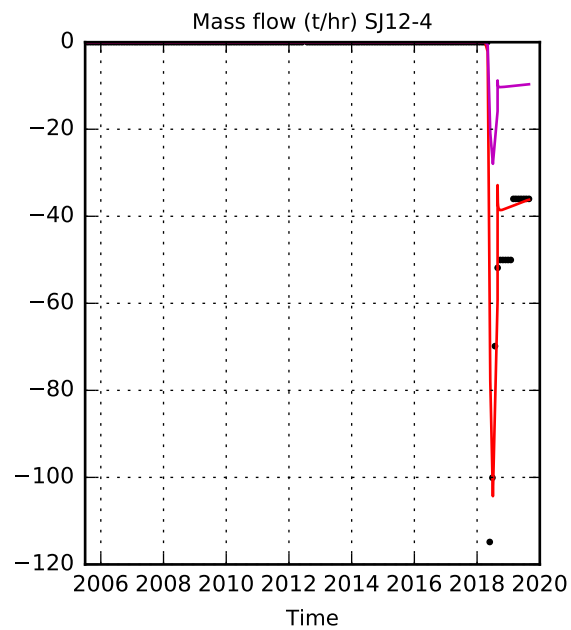
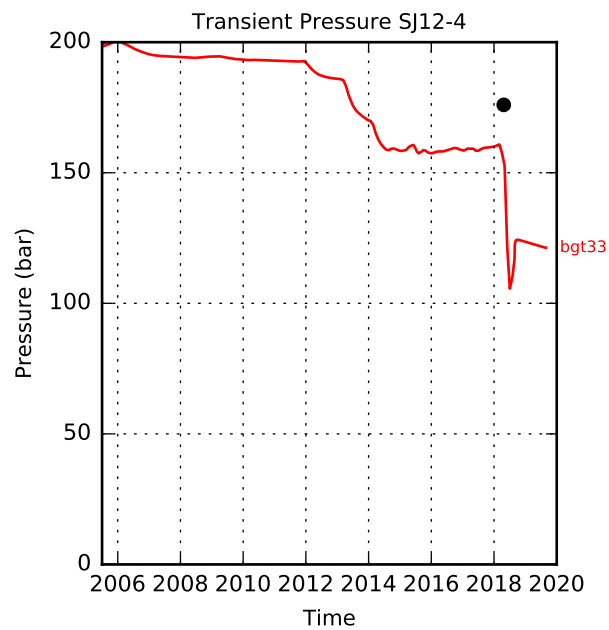
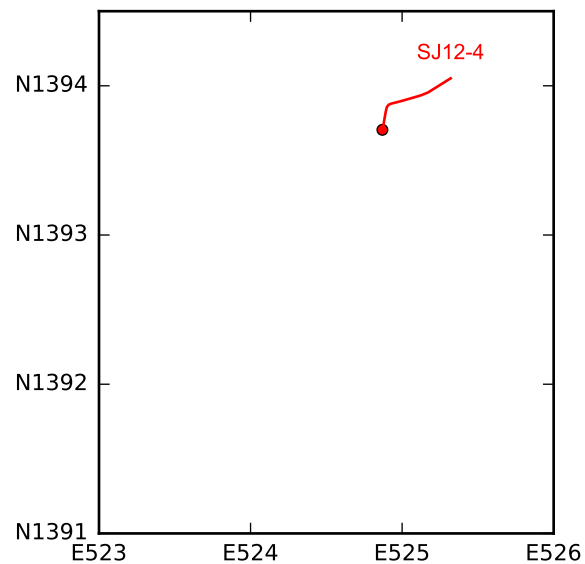


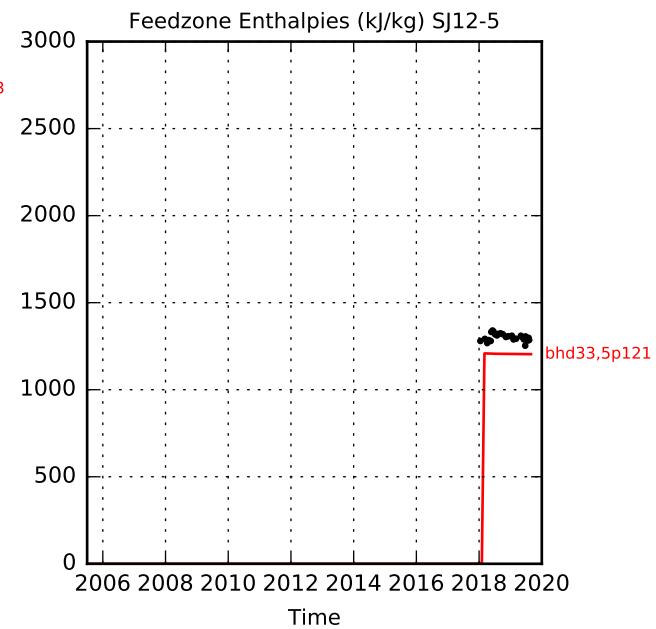
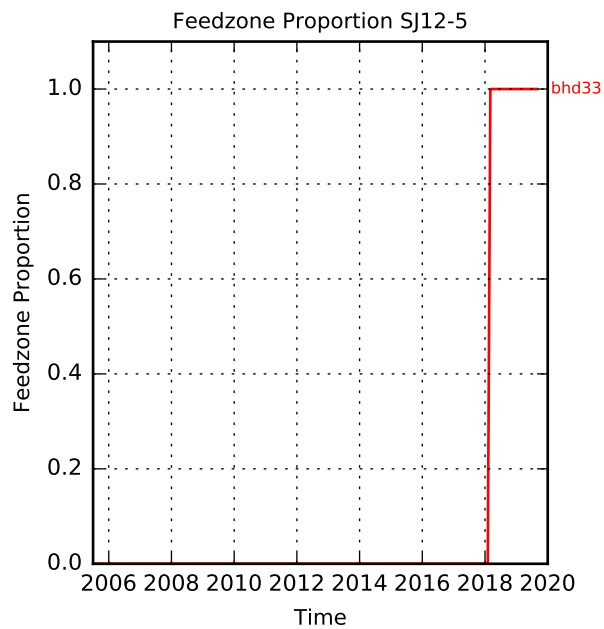
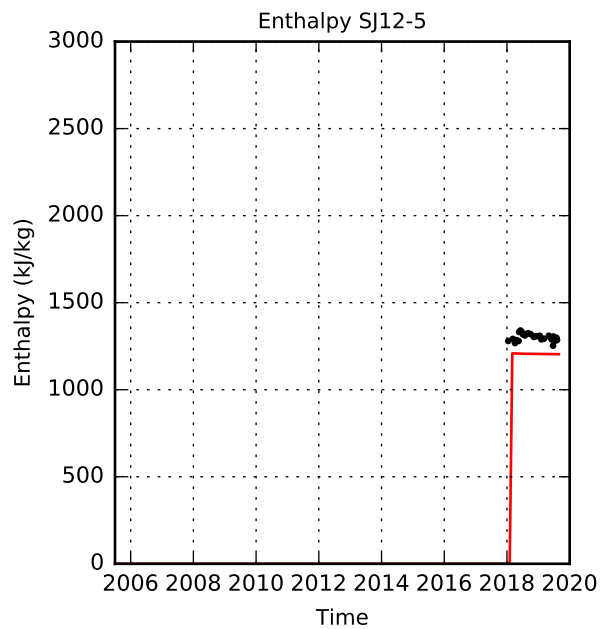
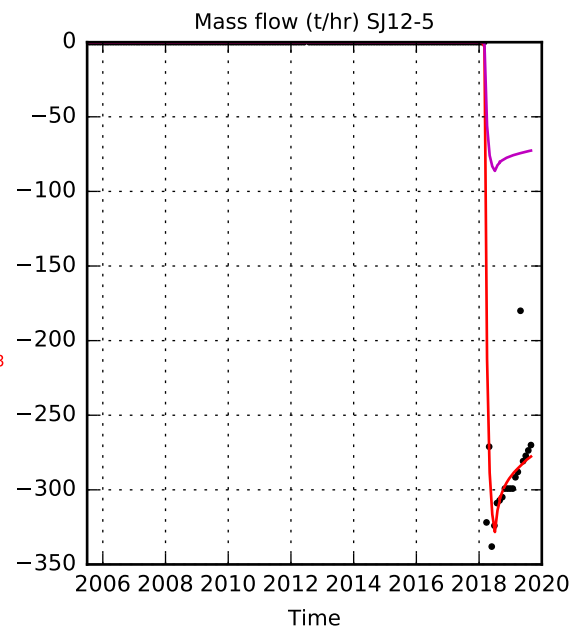
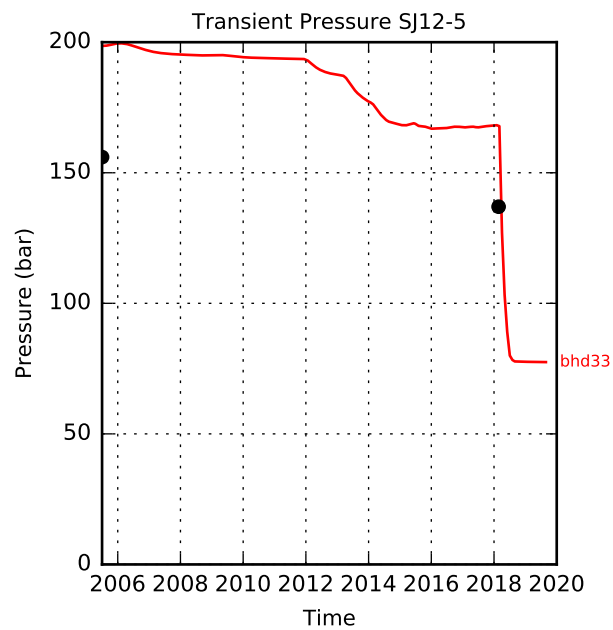
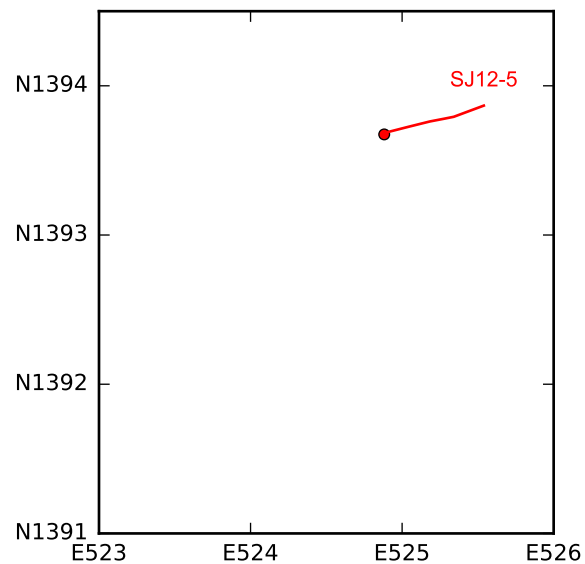


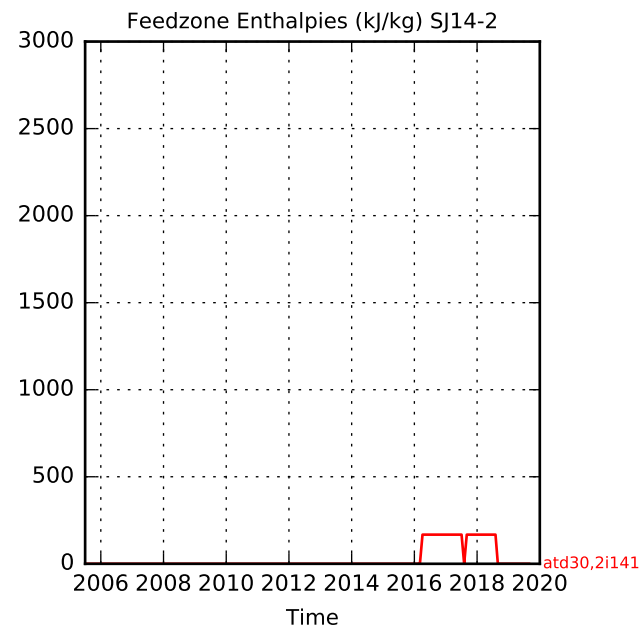
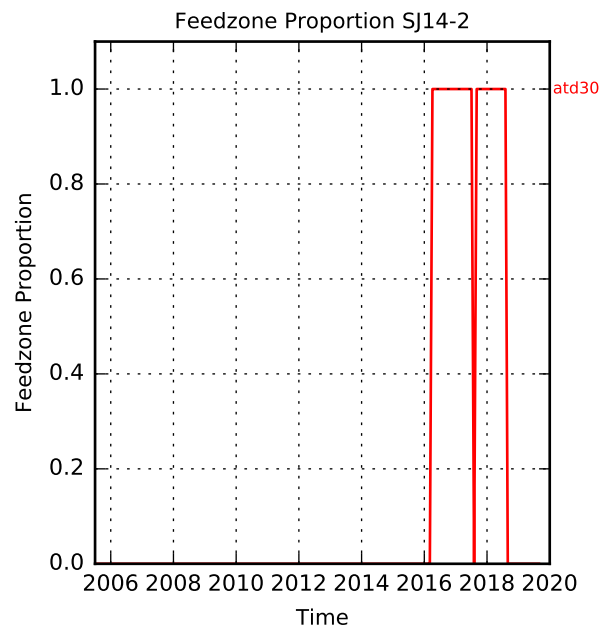
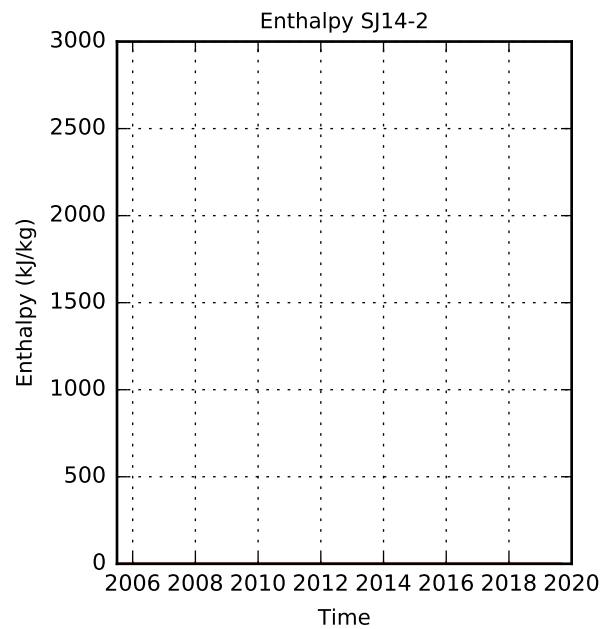
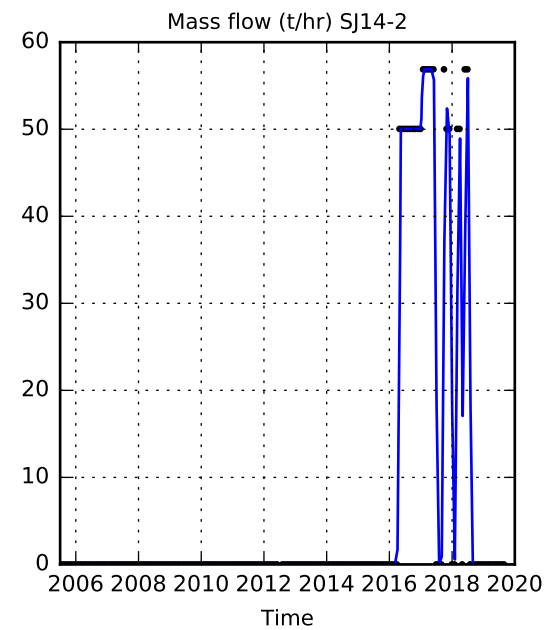
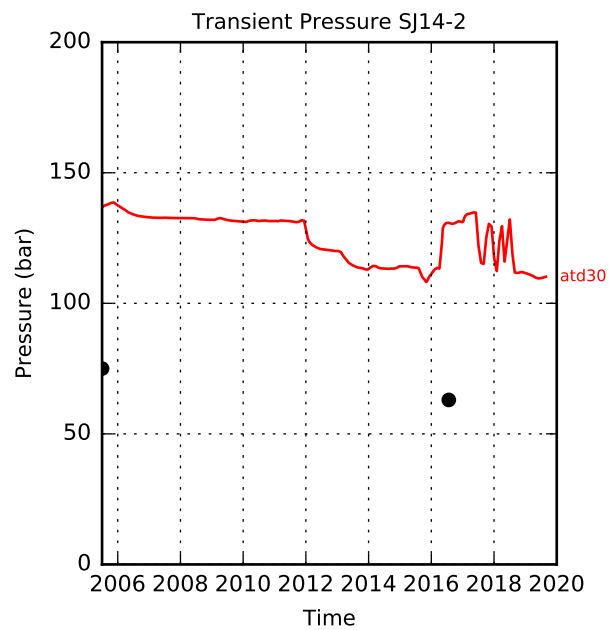
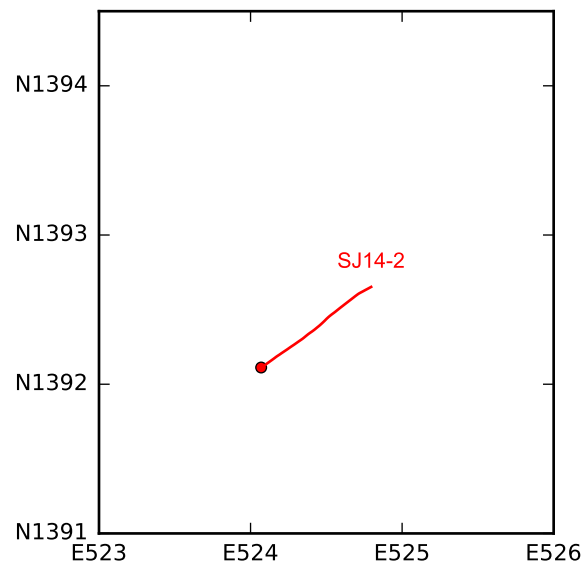


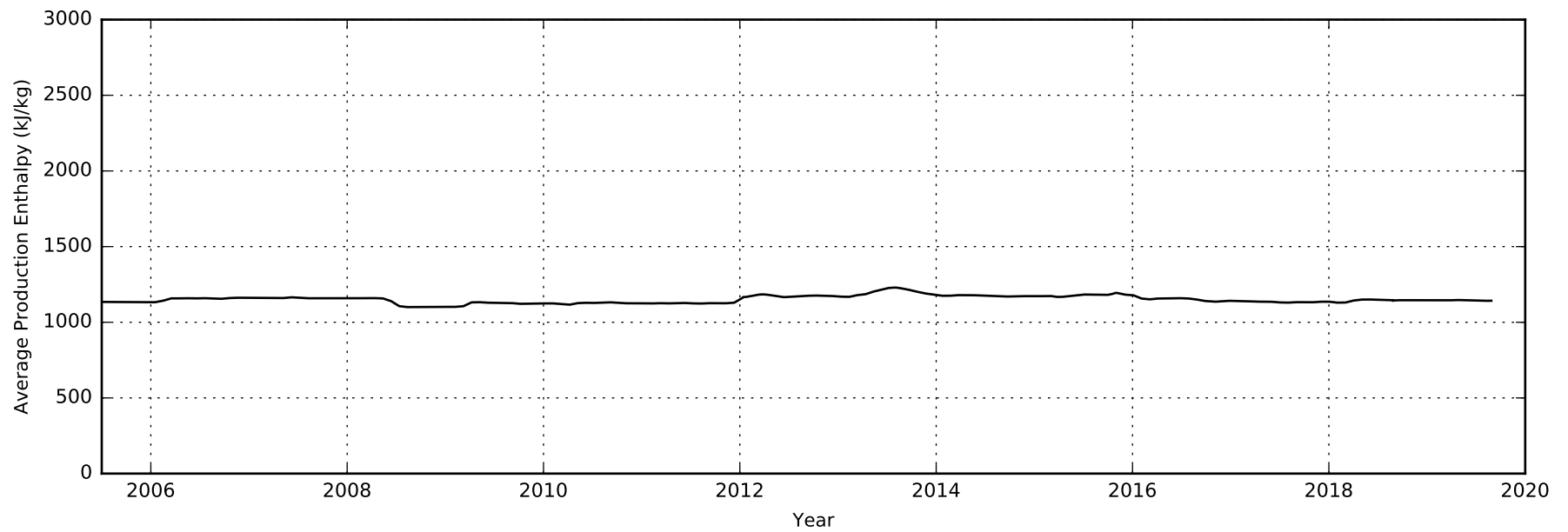
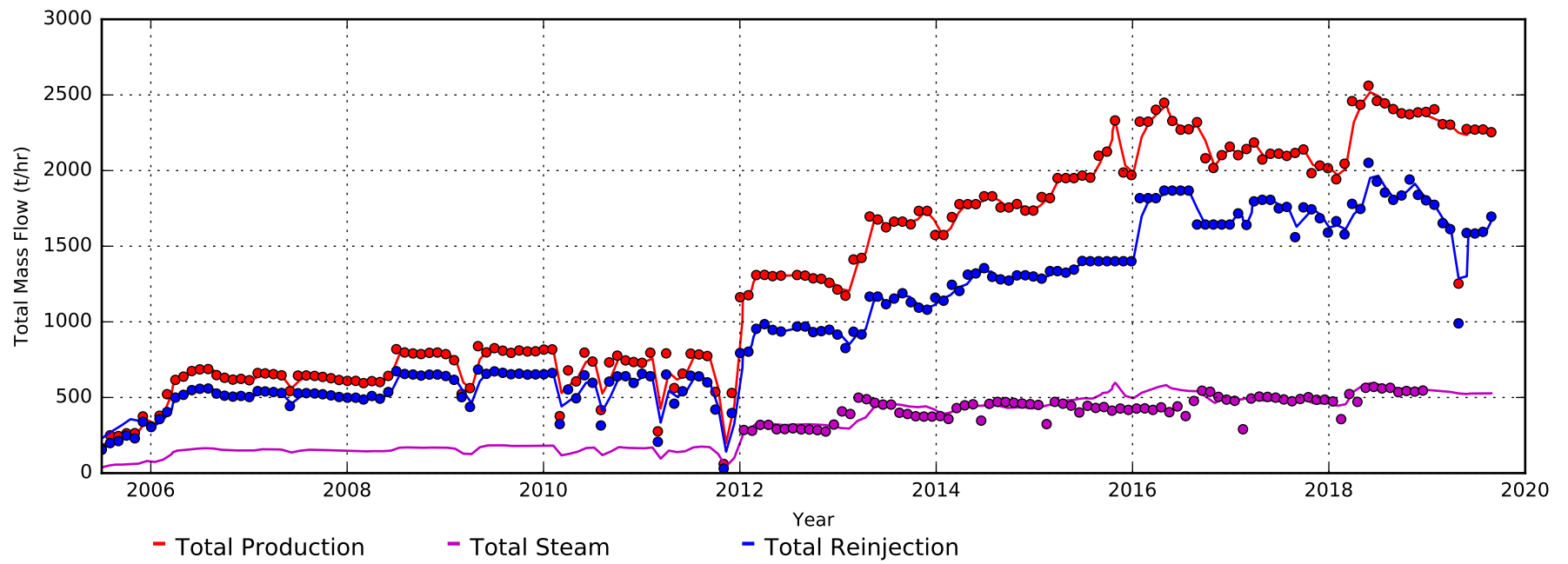




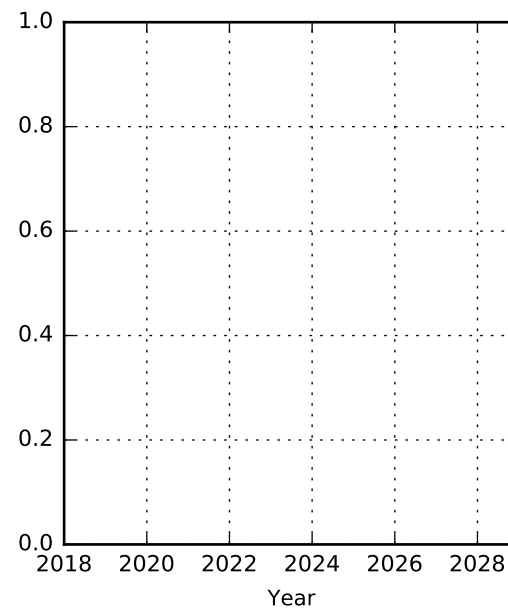
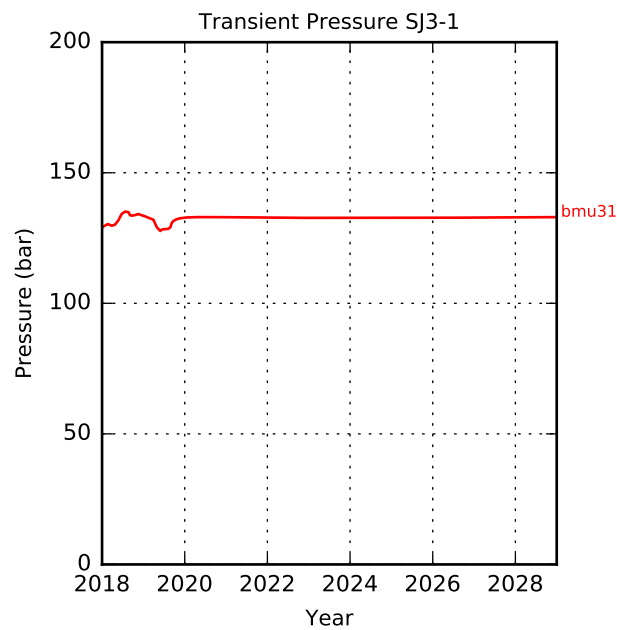
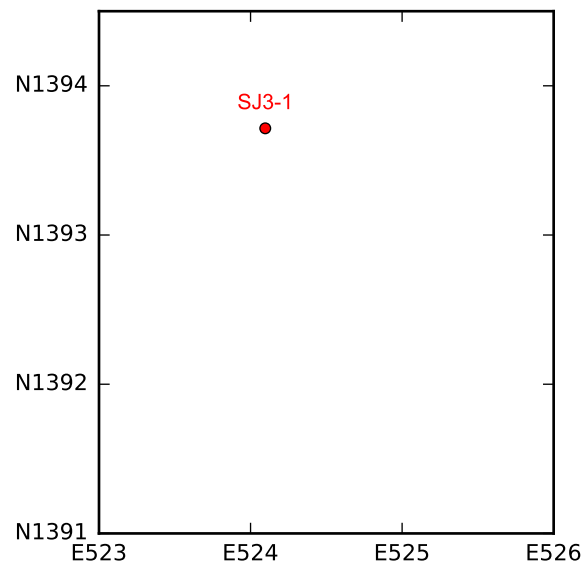






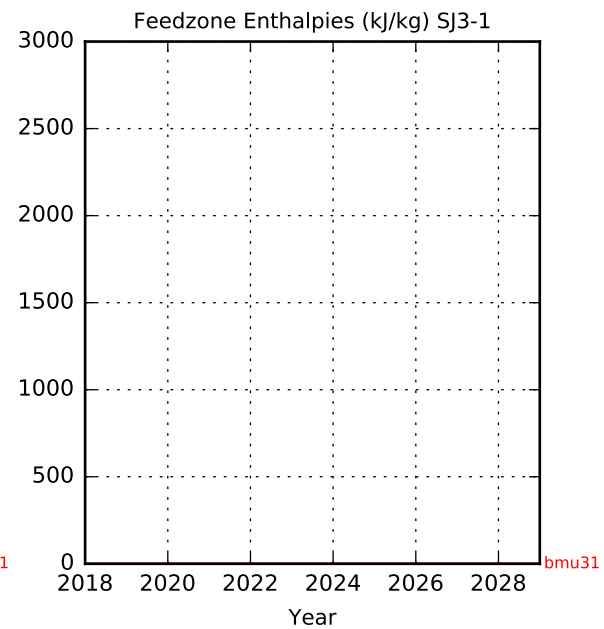
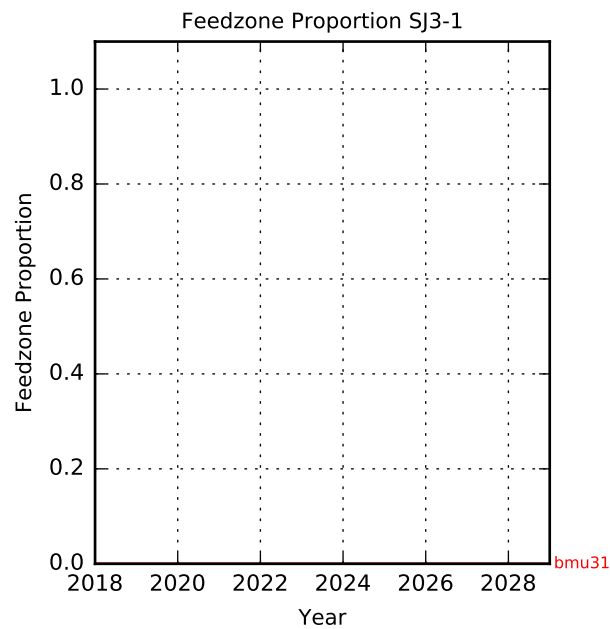
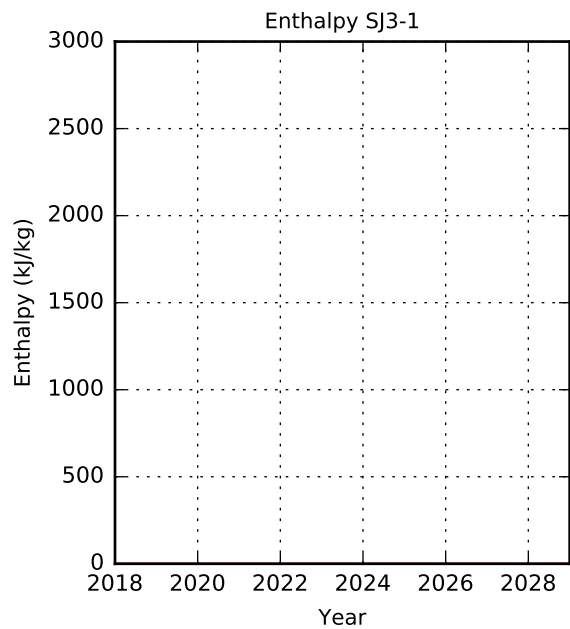


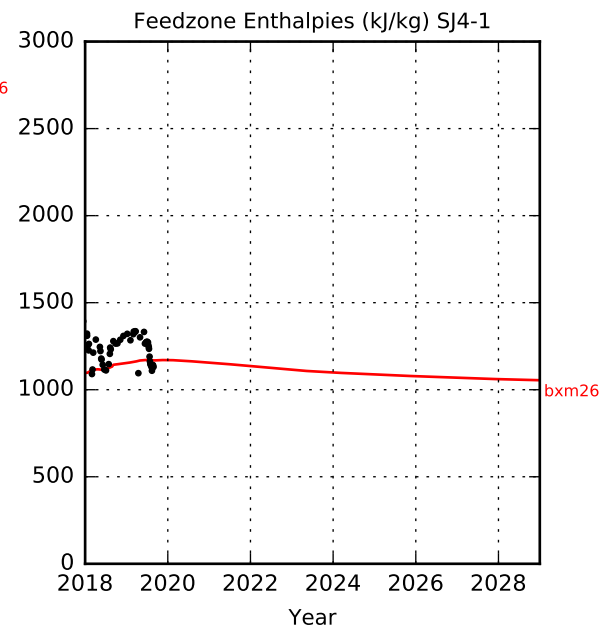
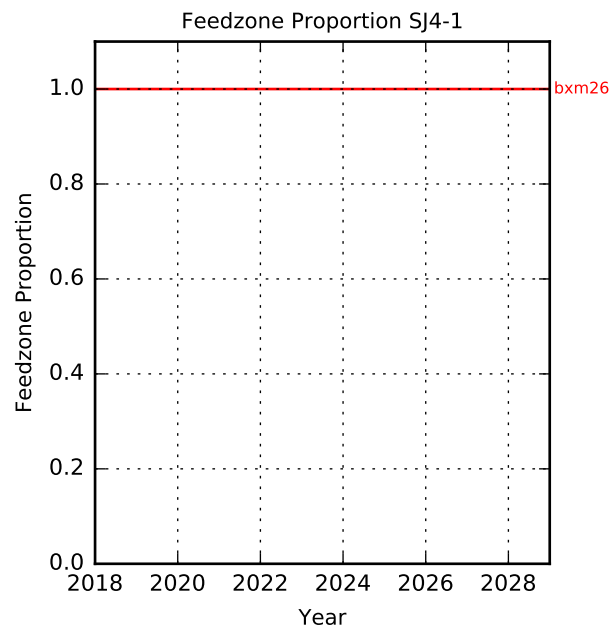
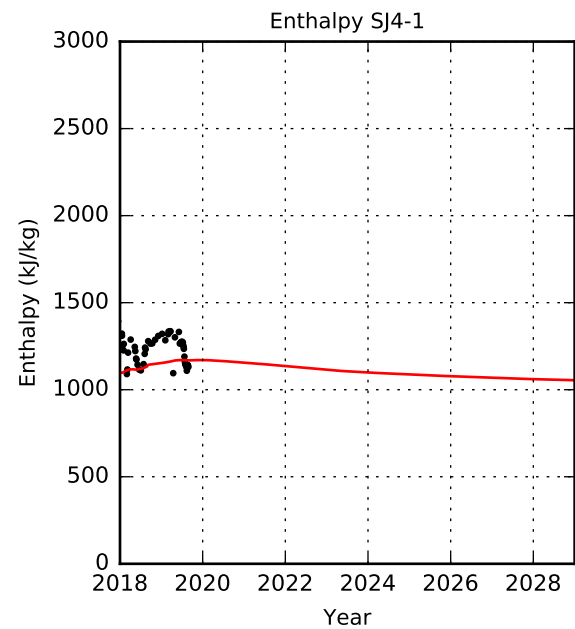
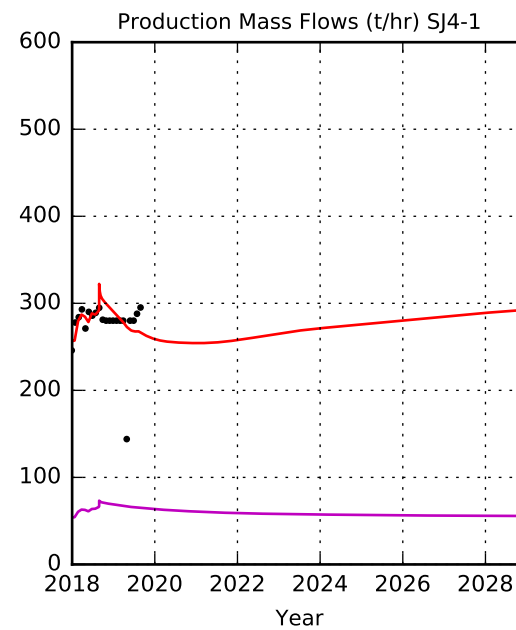
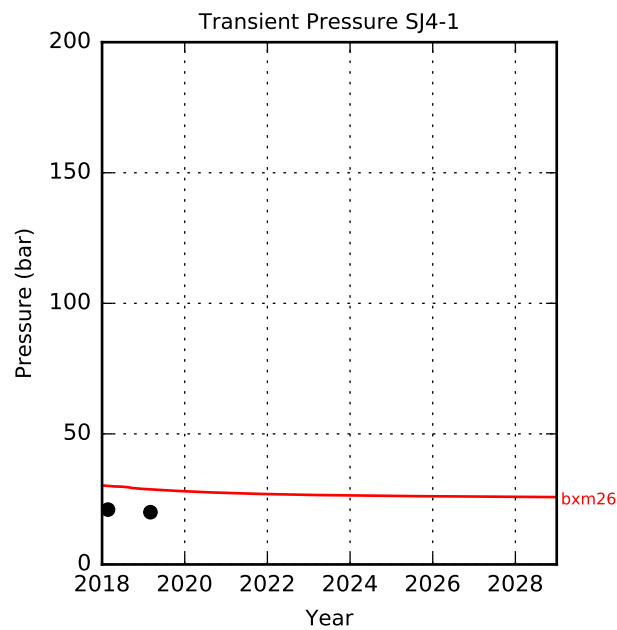
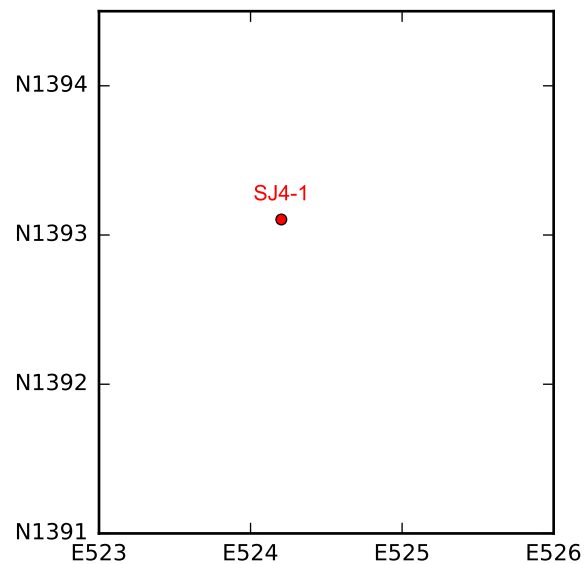
Appendix C. Future Scenario 001 Results

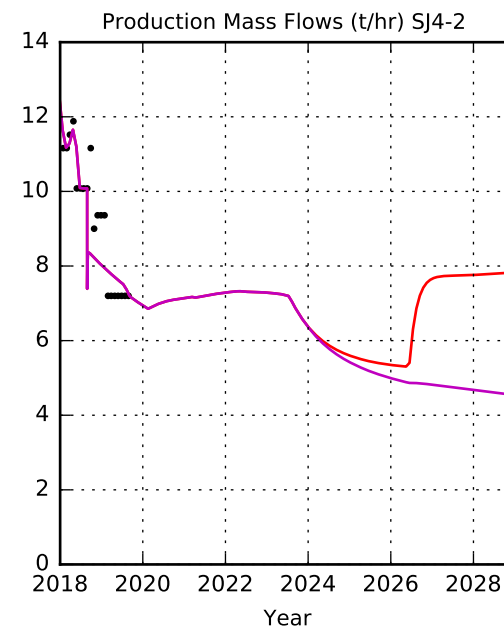
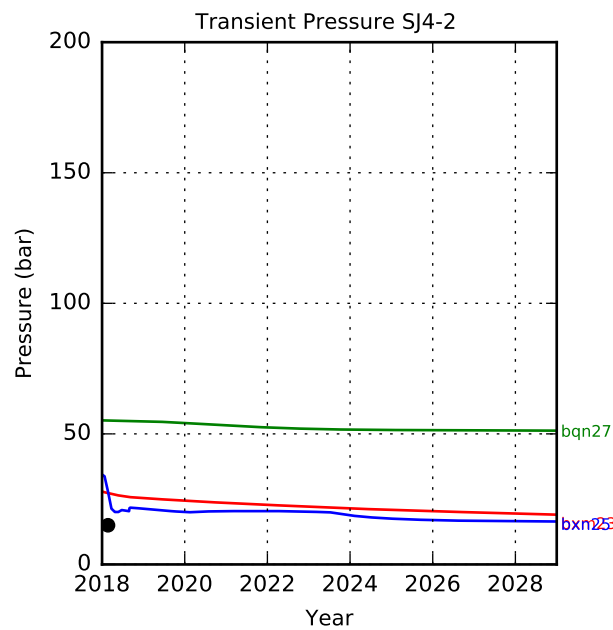
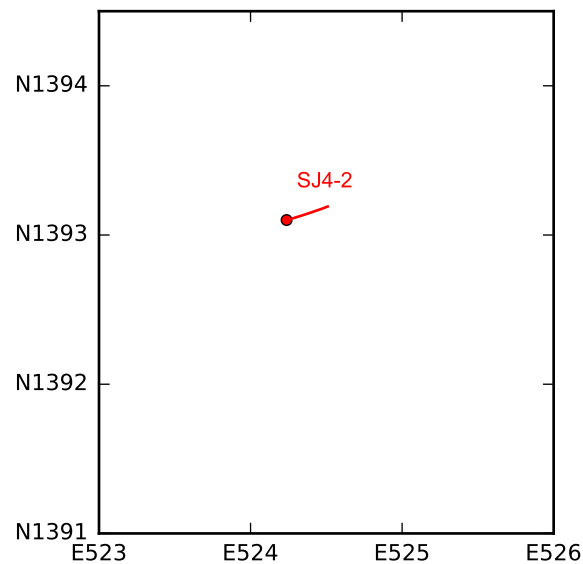


Feedzone Elevations

-1500.0 masl

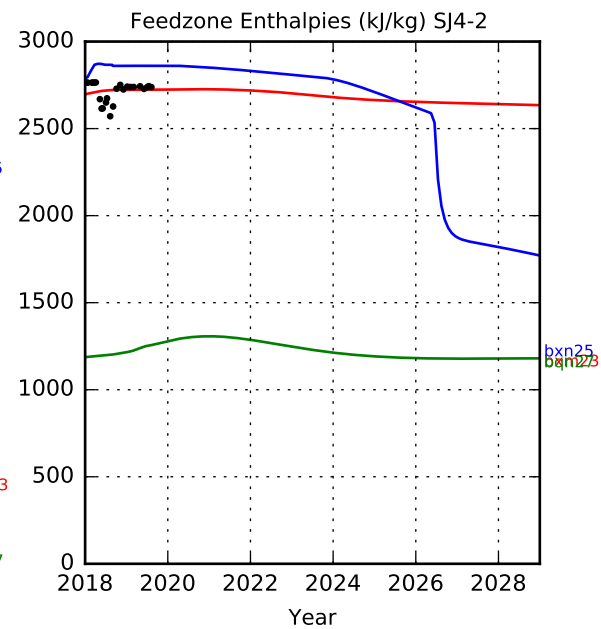
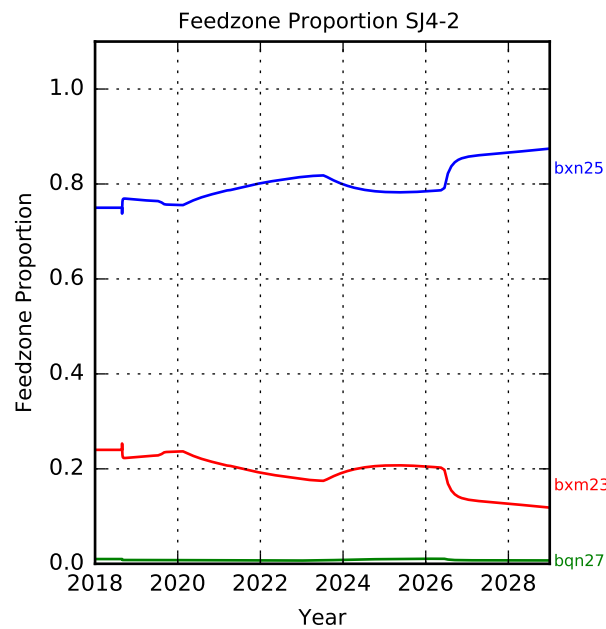
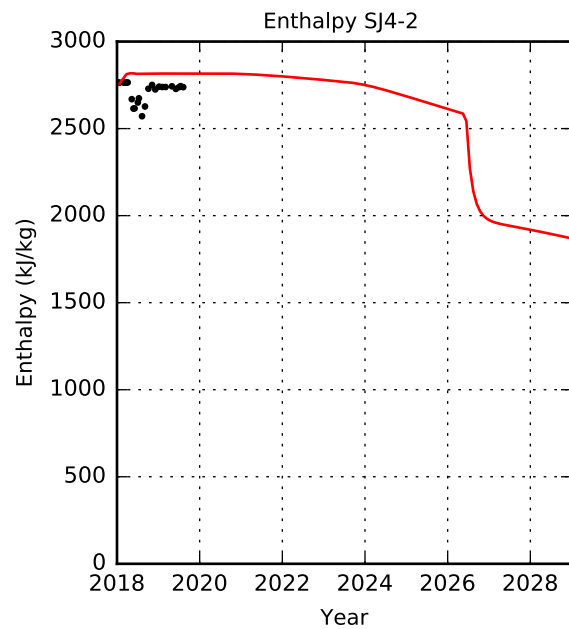


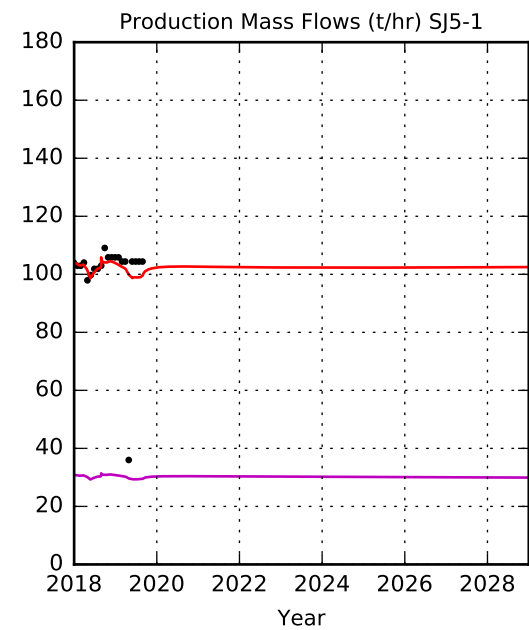
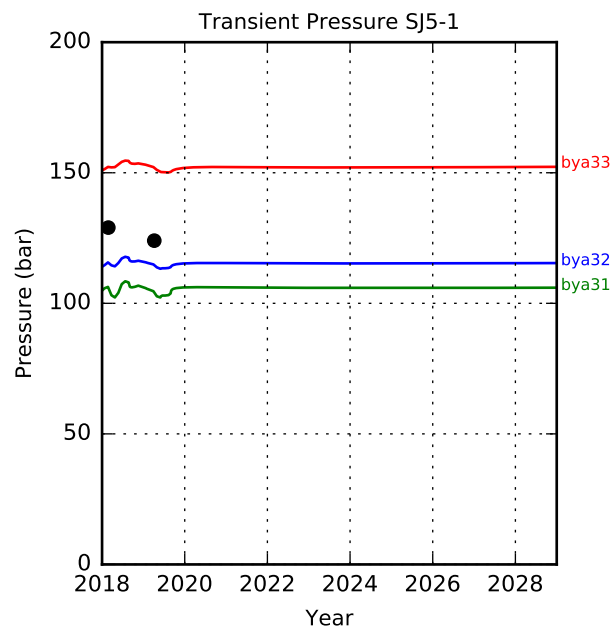
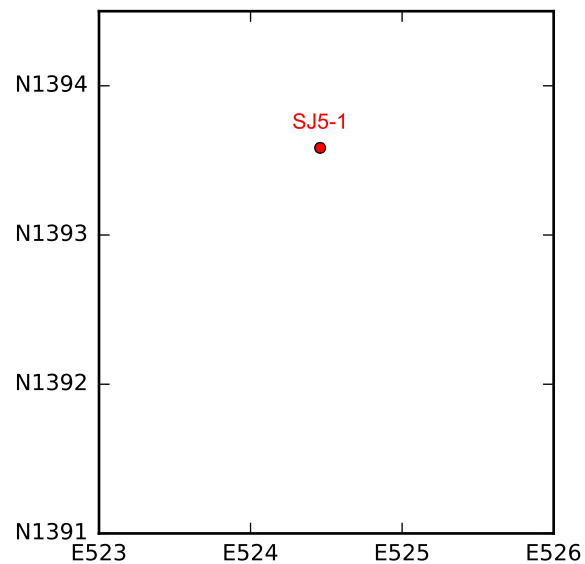




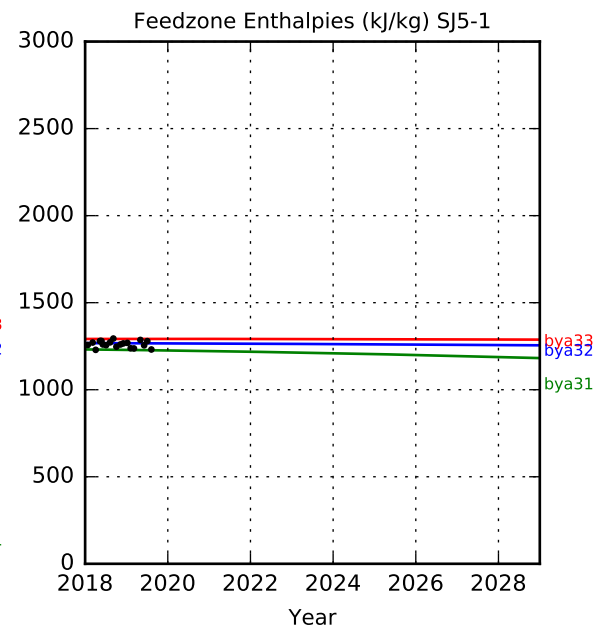
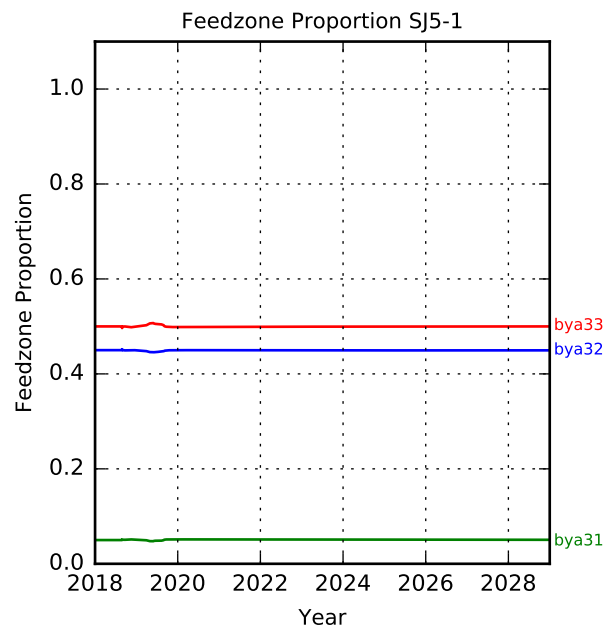
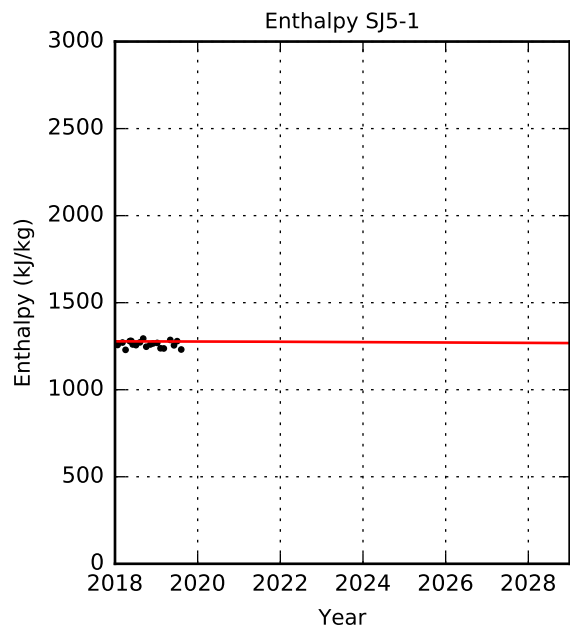
Feedzone Elevations
-150.0 masl -375.0 masl -700.0 masl

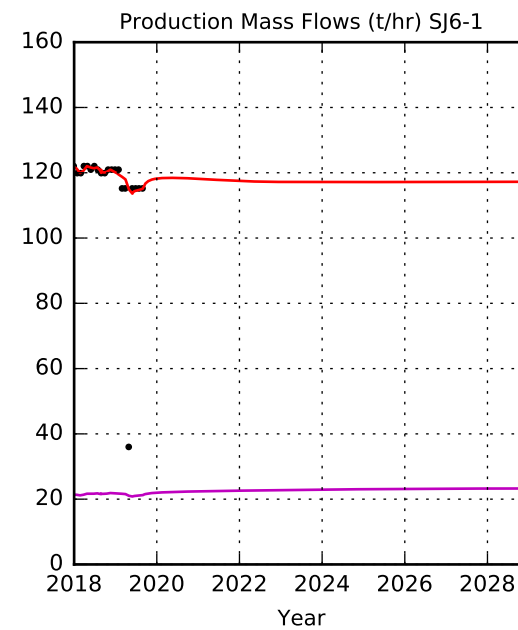
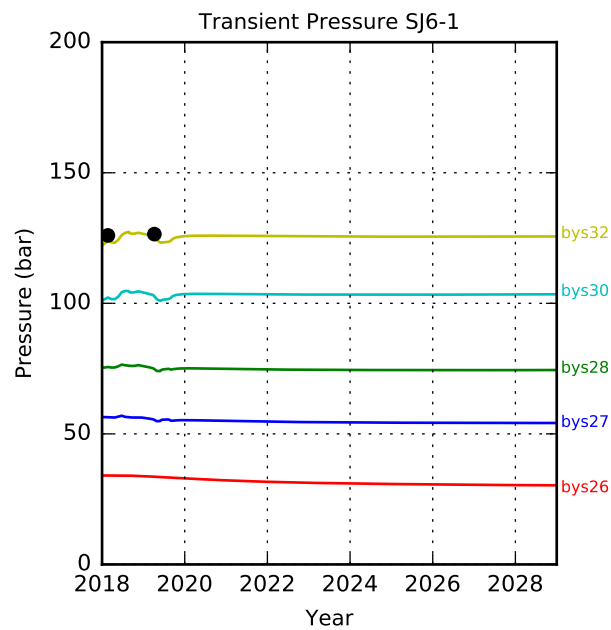
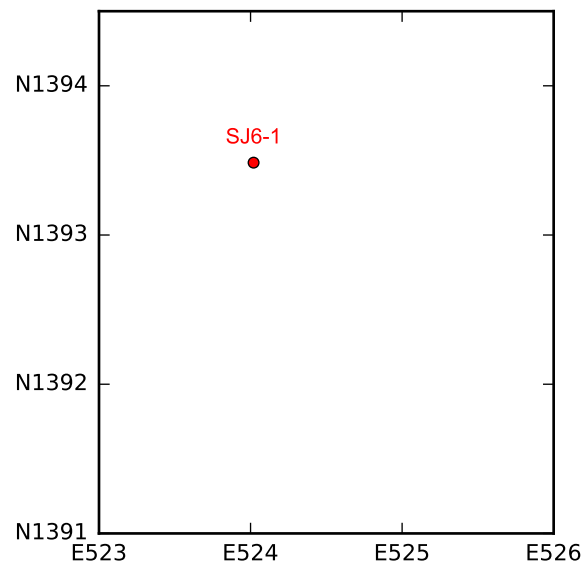
— Total Mass Flow — Steam Flow





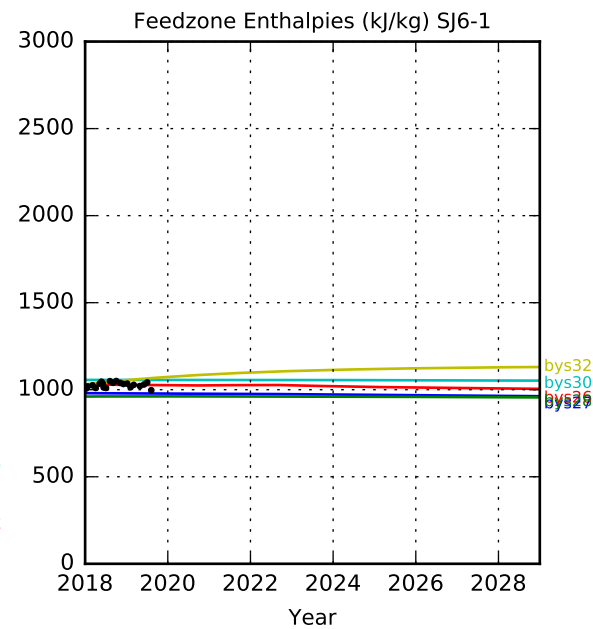
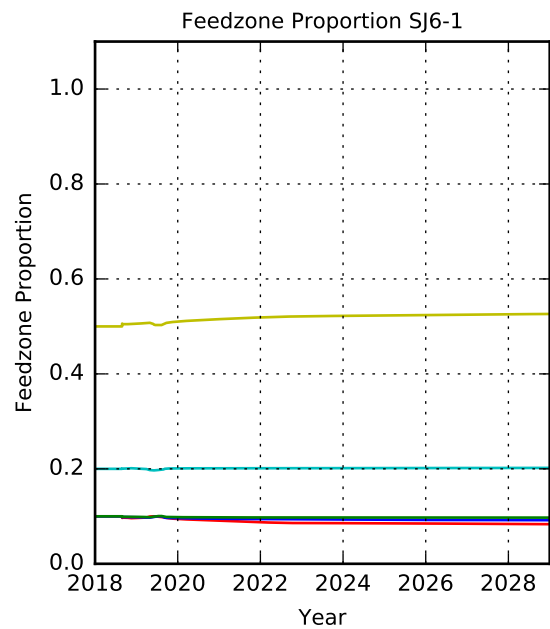
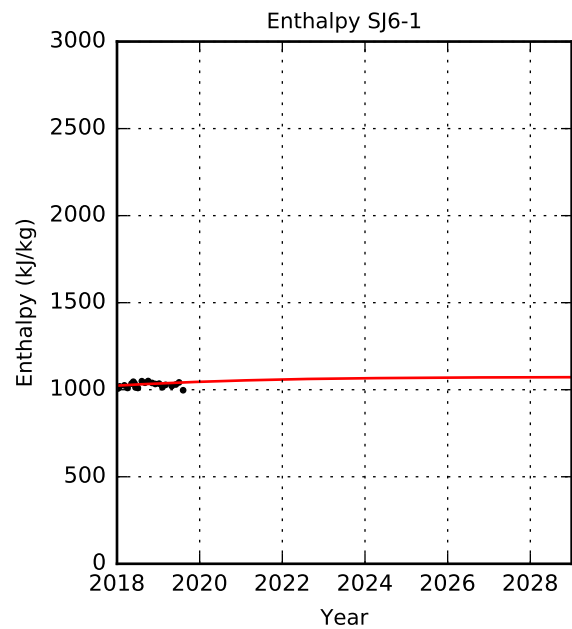
Feedzone Elevations
-2000.0 masl -1700.0 masl -1500.0 masl

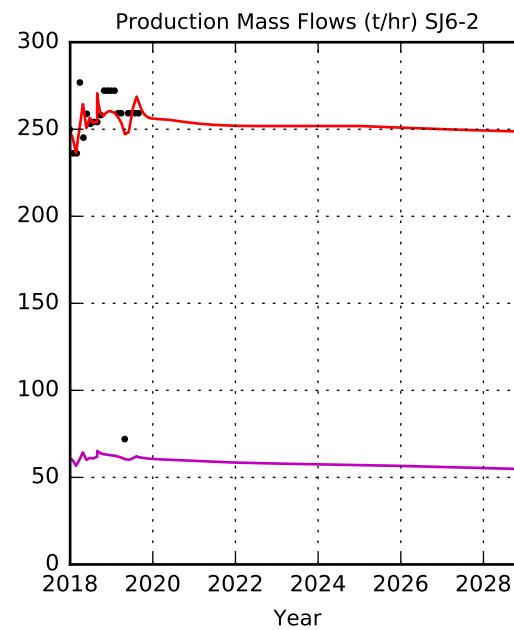
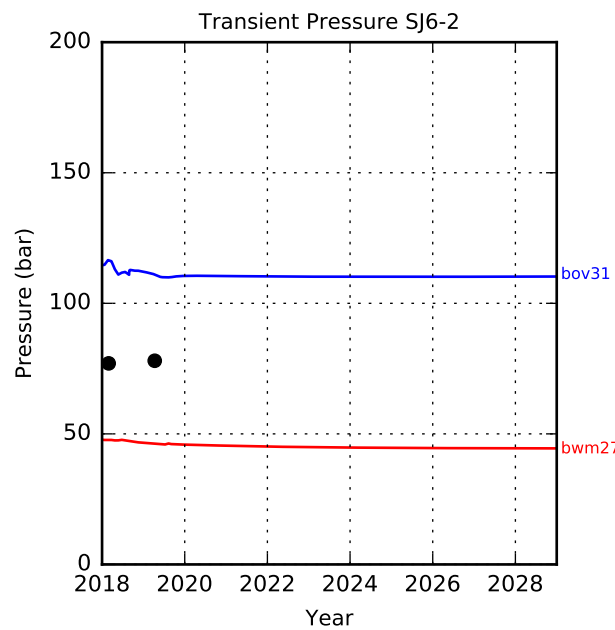
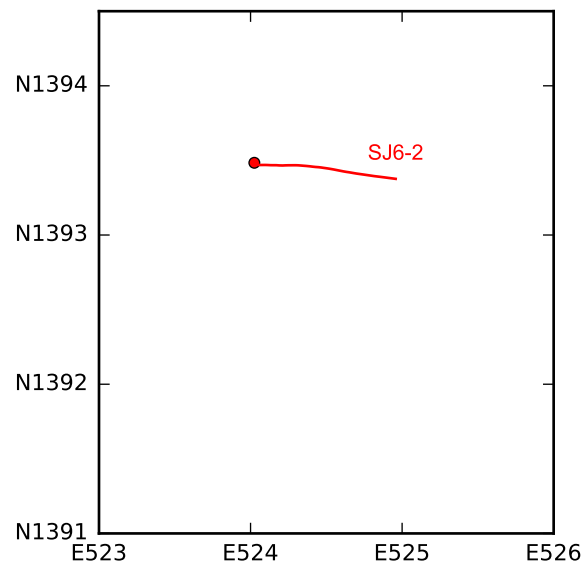




Feedzone Elevations

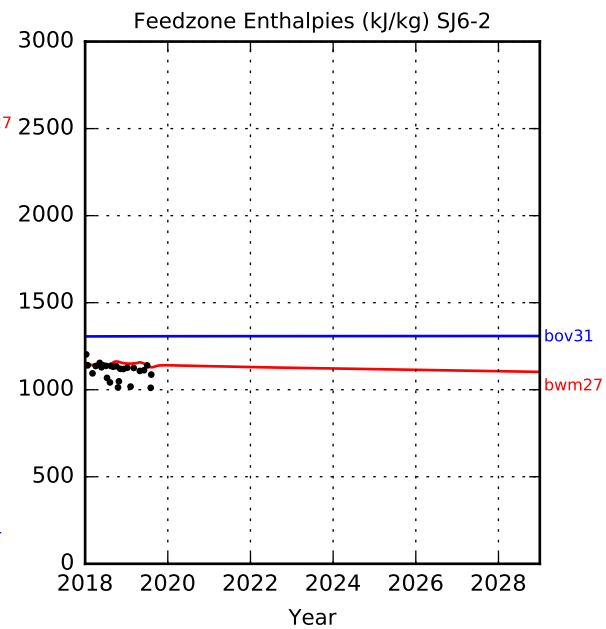
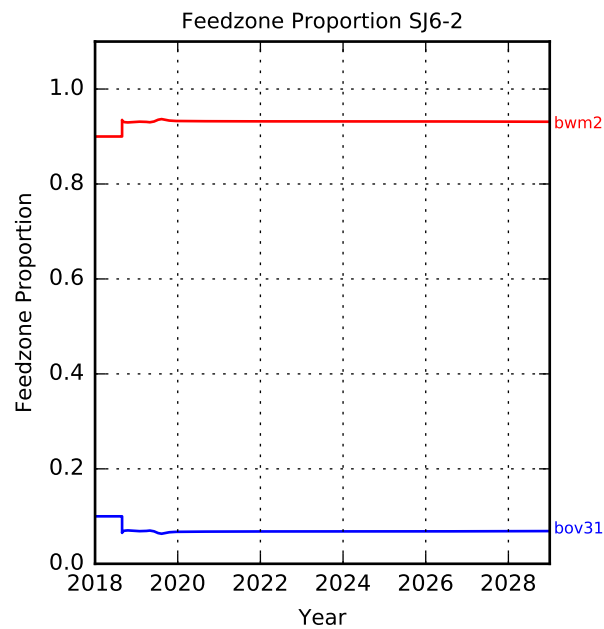
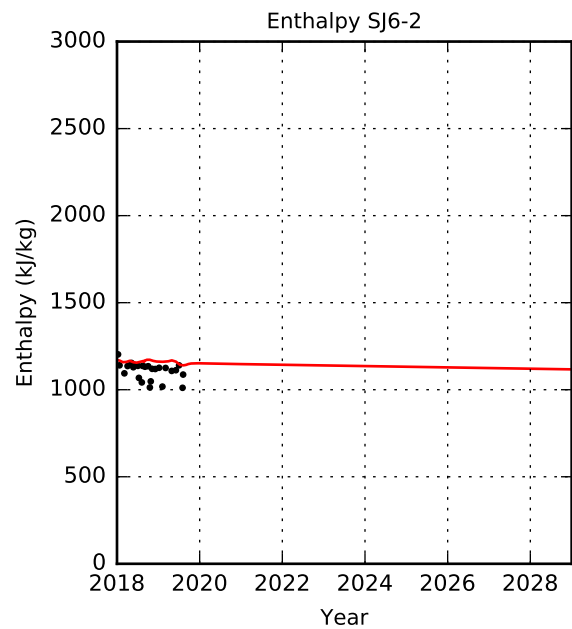
- 525.0 masl
- 700.0 masl
- 900.0 masl
- 1300.0 masl
- 1700.0 masl

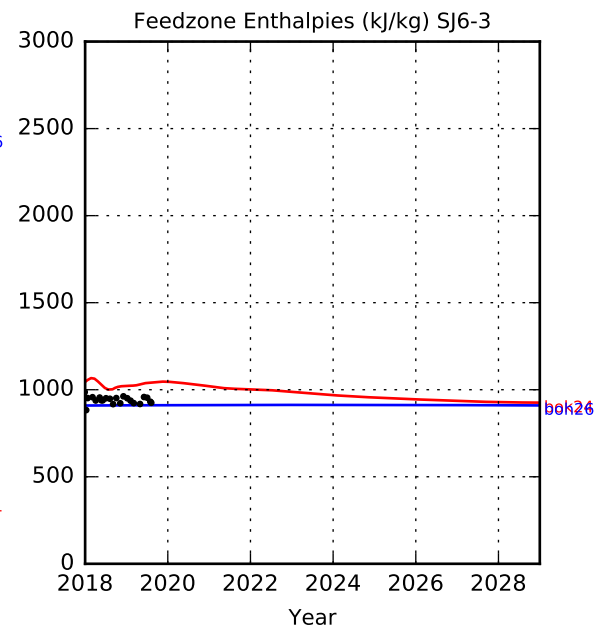
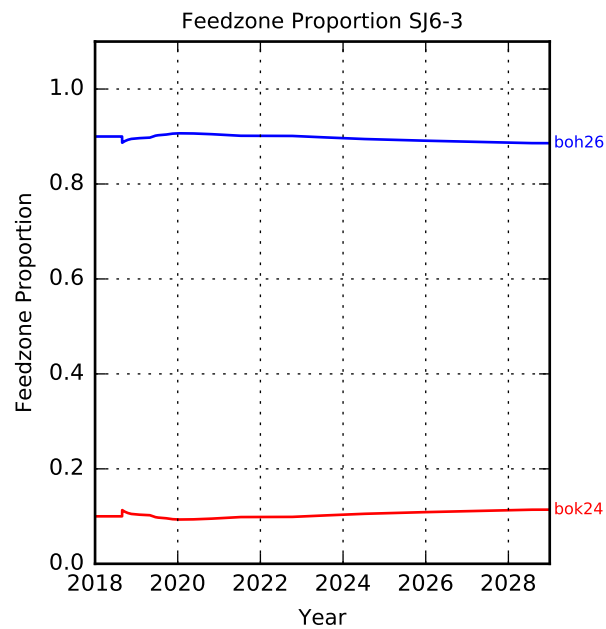
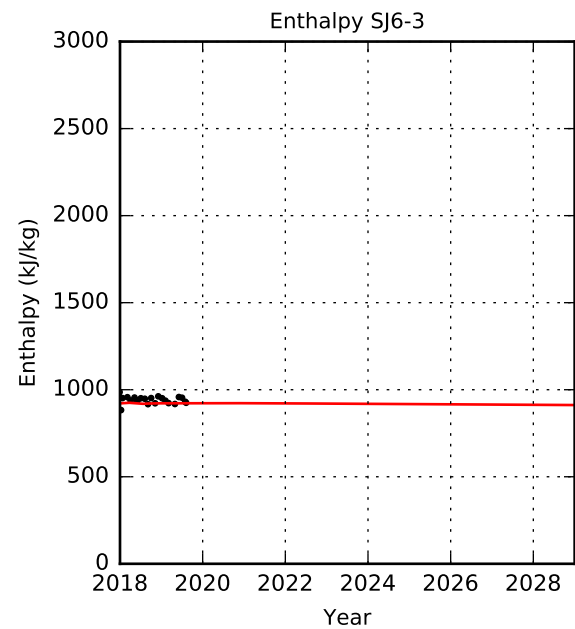
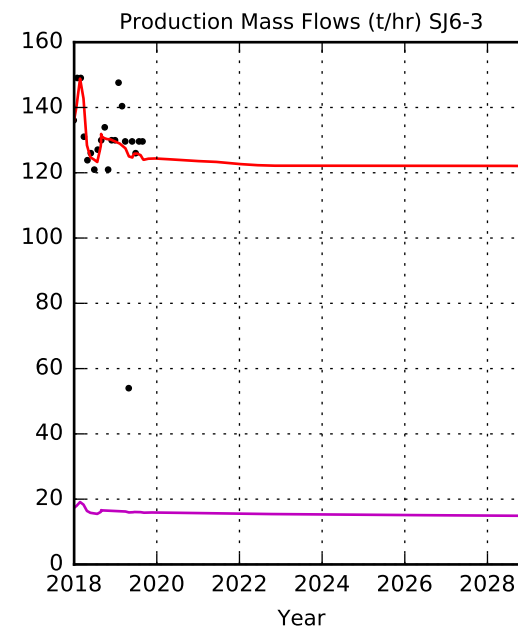
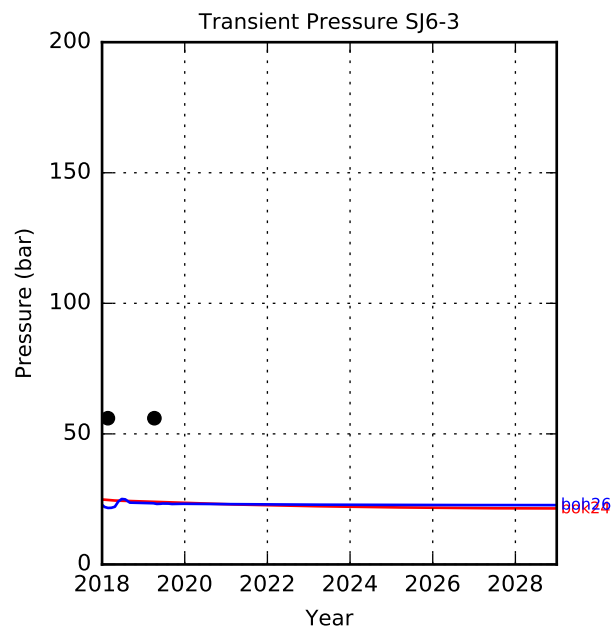
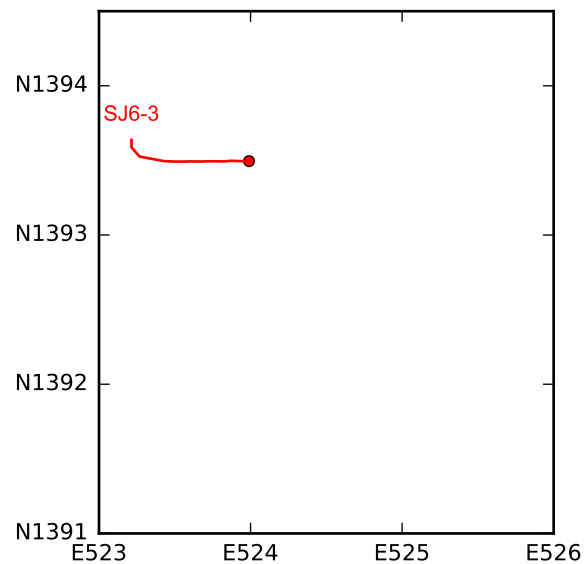


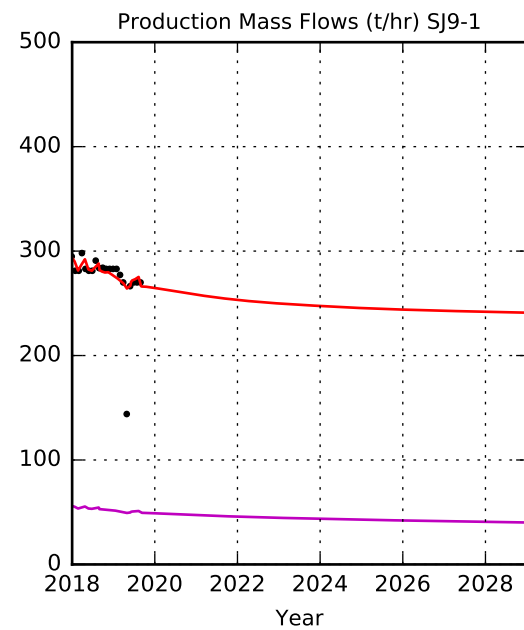
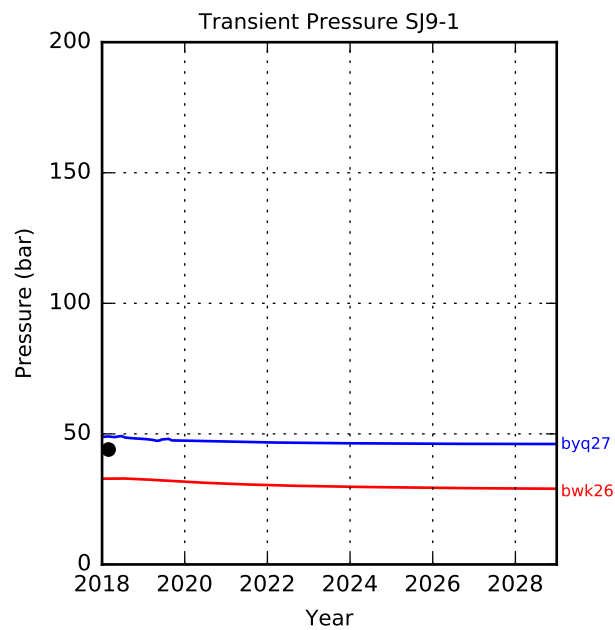
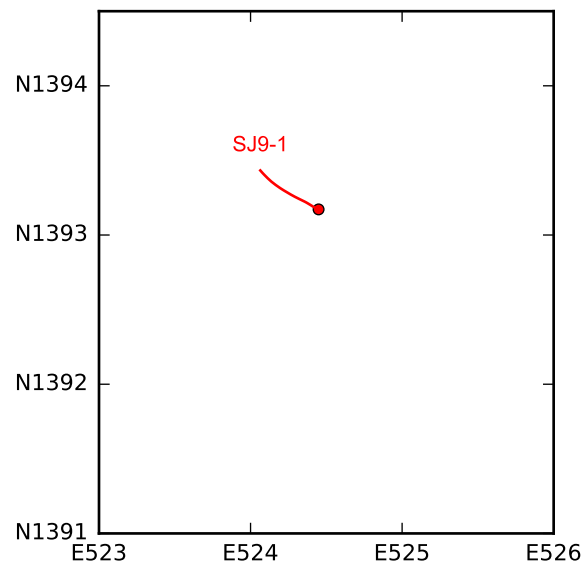


Feedzone Elevations
-700.0 masl -1500.0 masl

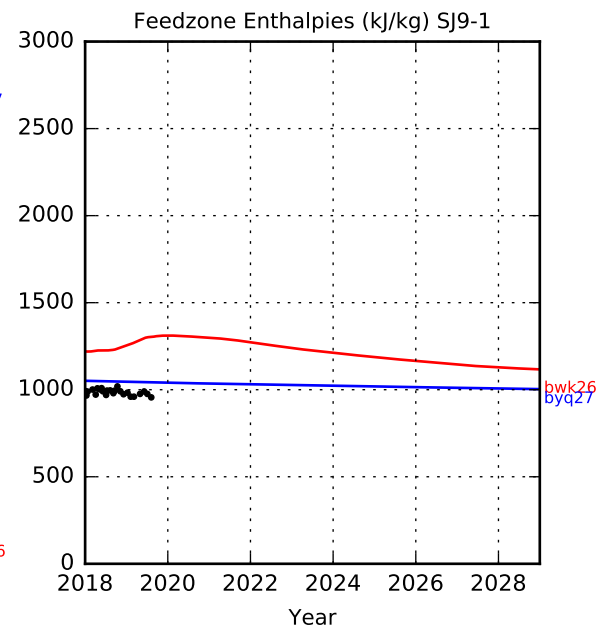
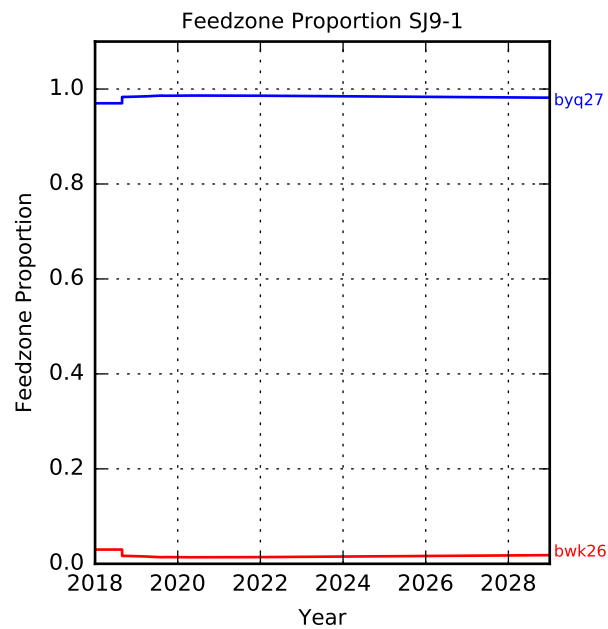
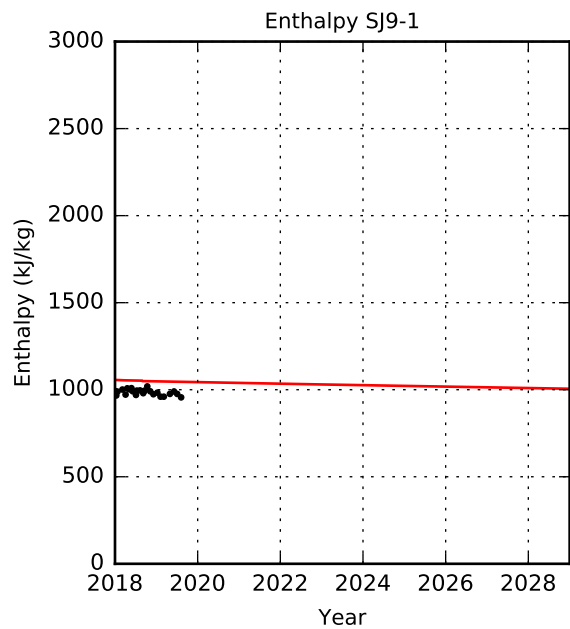
— Total Mass Flow — Steam Flow

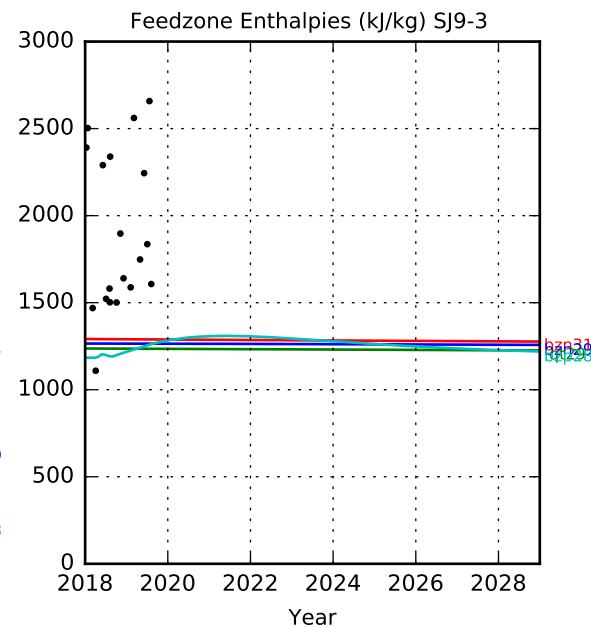
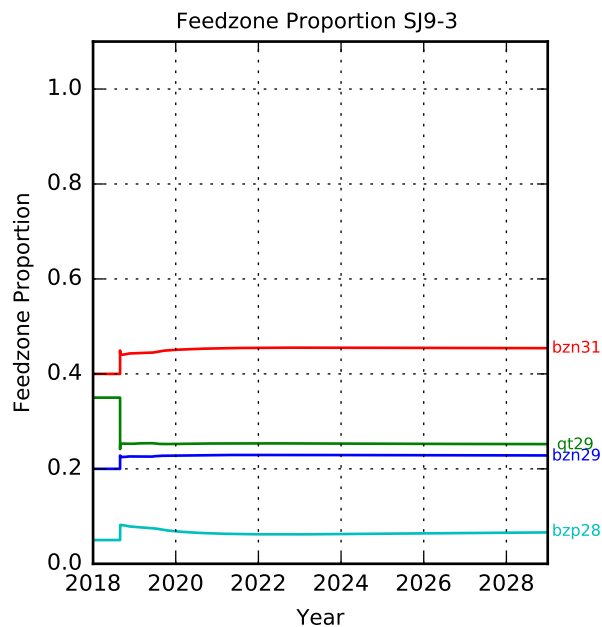
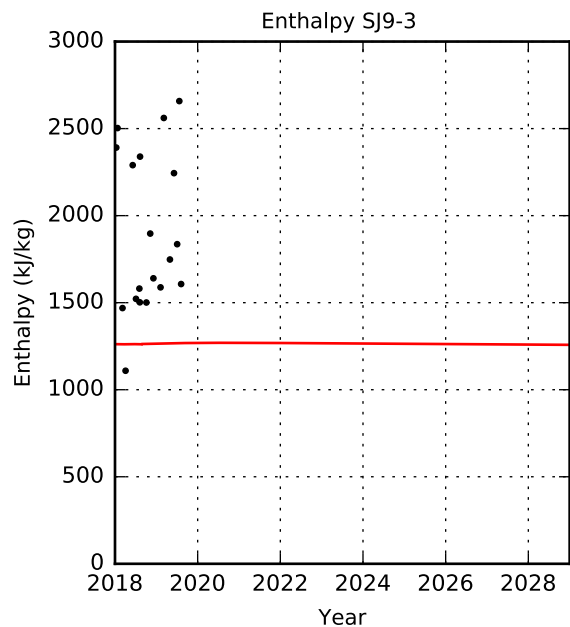
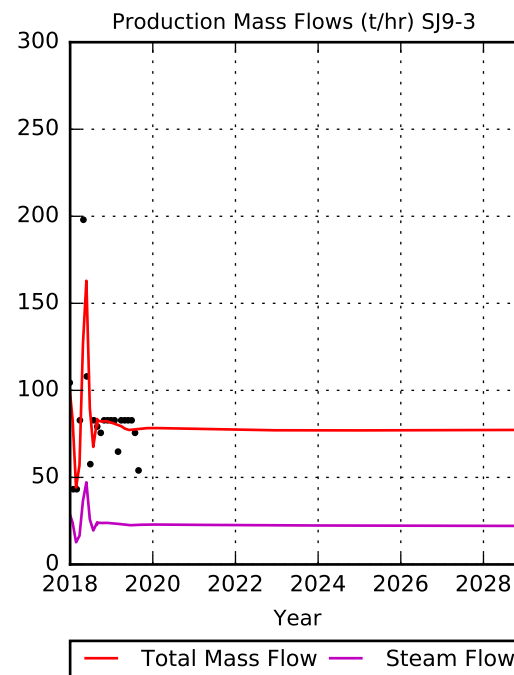
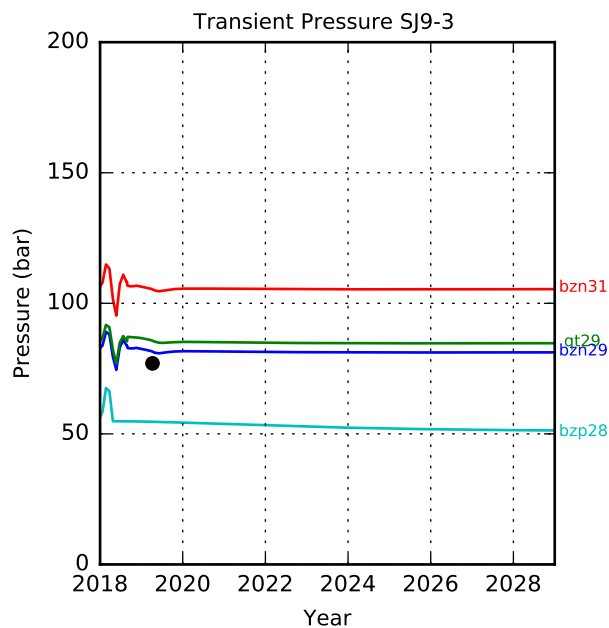
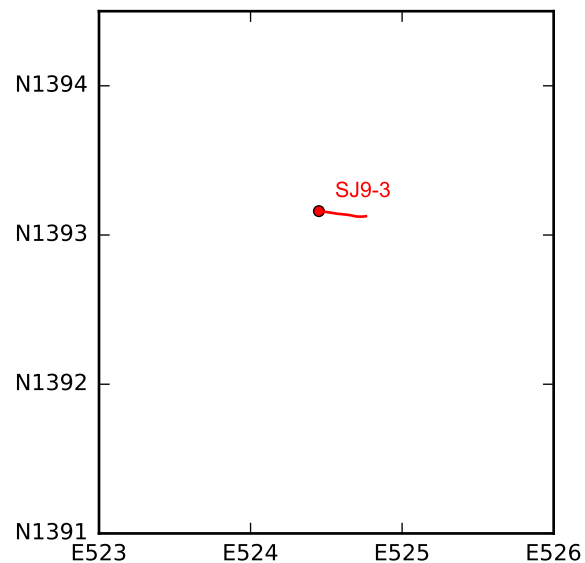


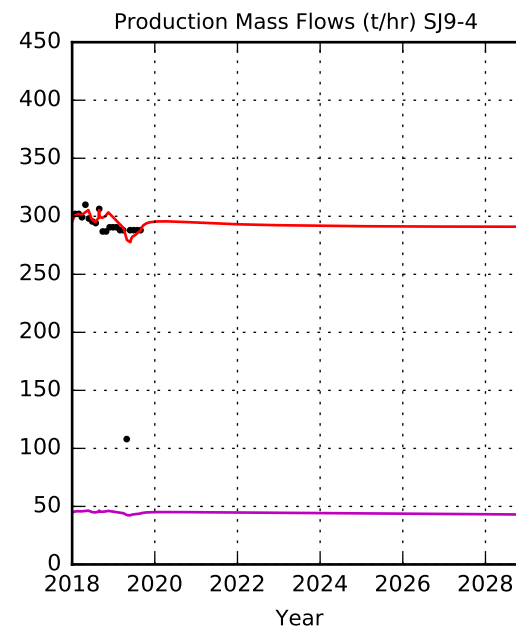
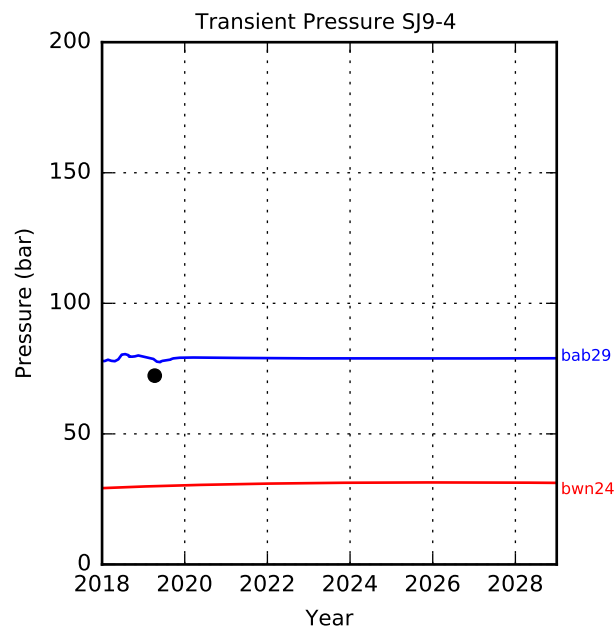
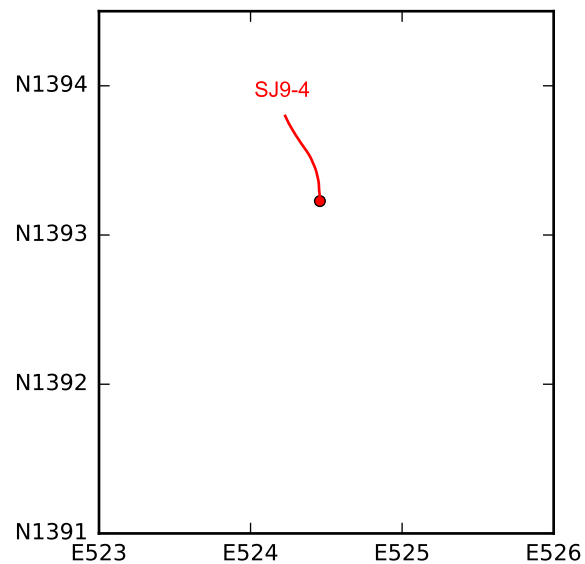




Feedzone Elevations
-525.0 masl -700.0 masl

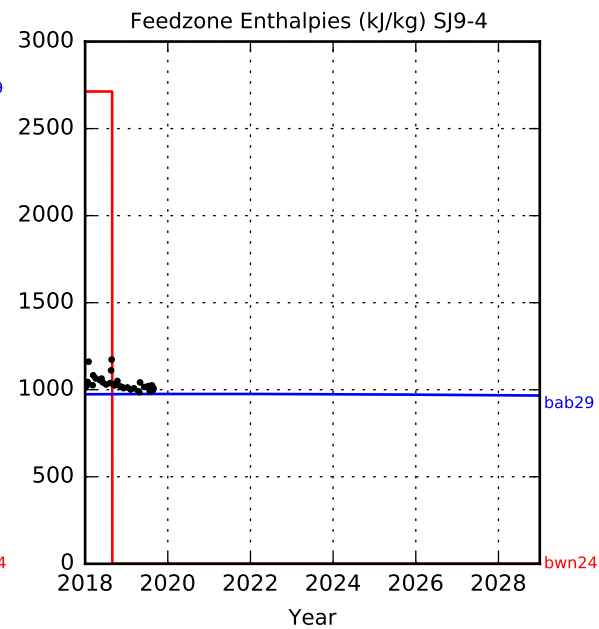
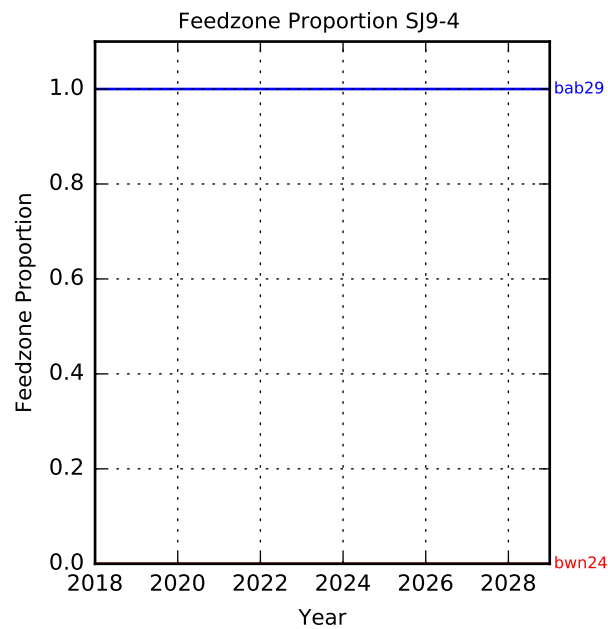
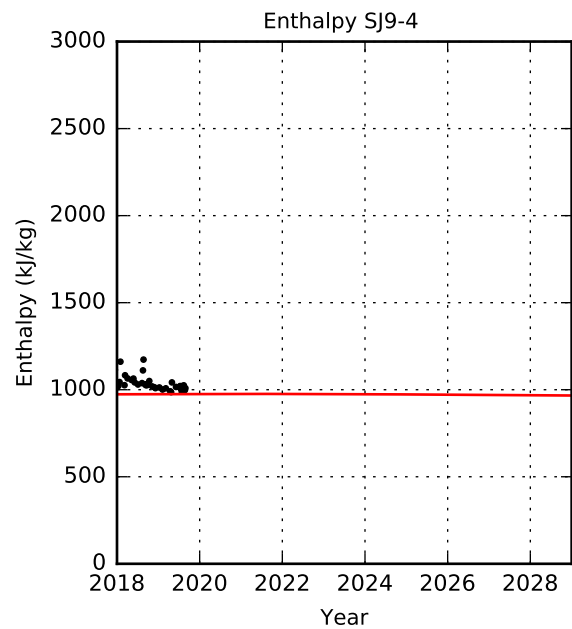


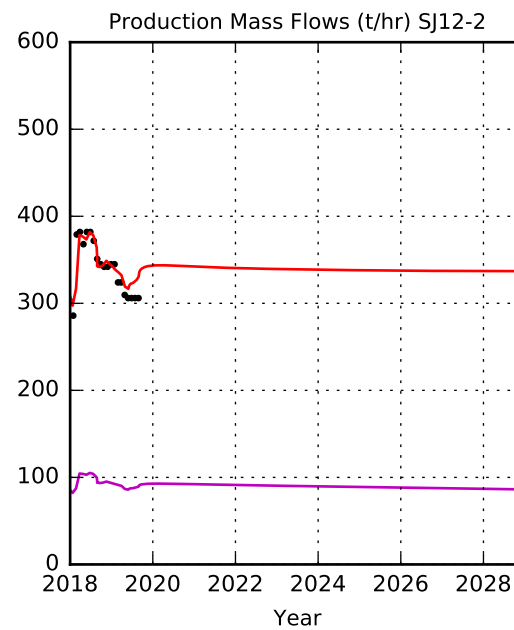
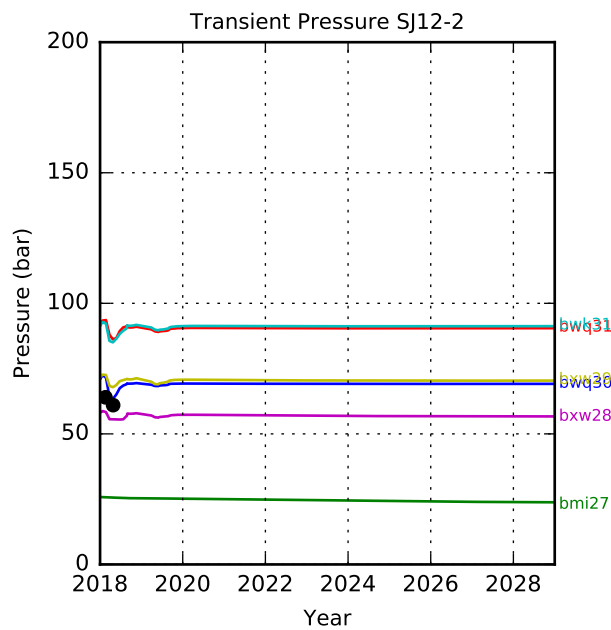
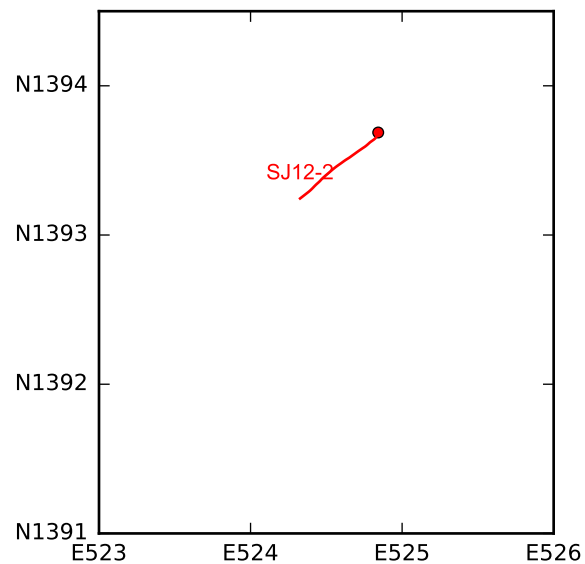




Feedzone Elevations
-250.0 masl -1100.0 masl

— Total Mass Flow — Steam Flow

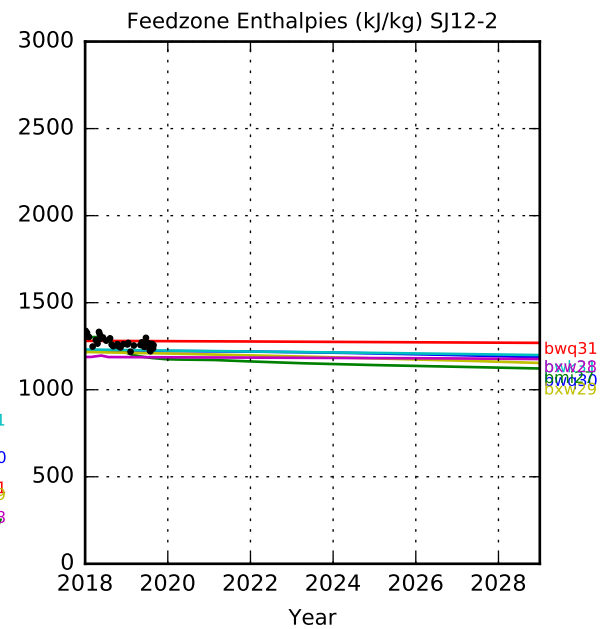
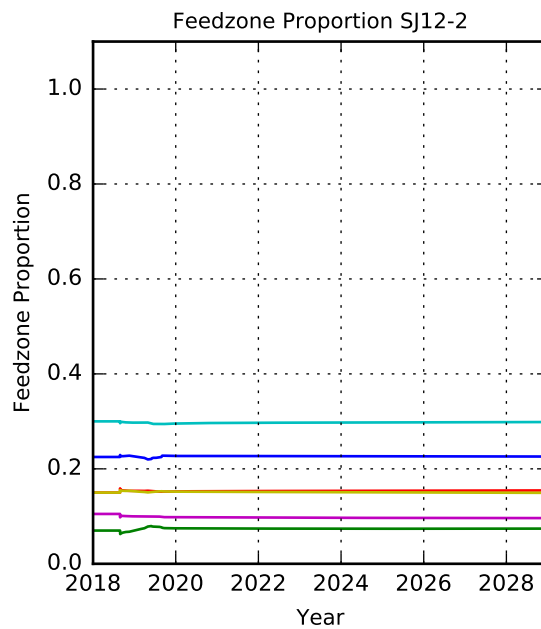
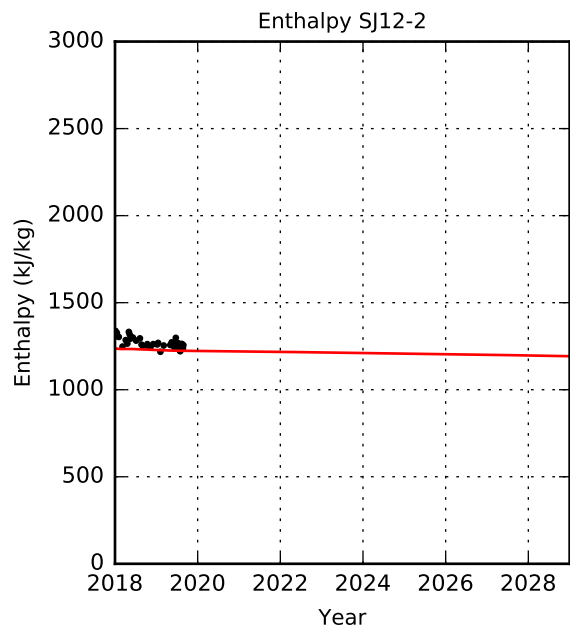


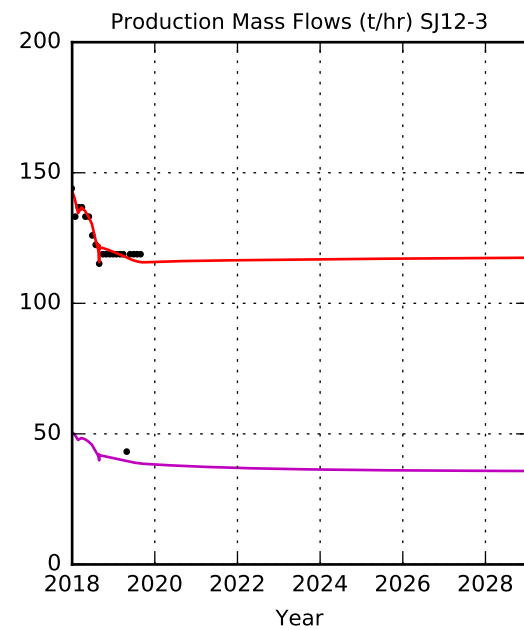
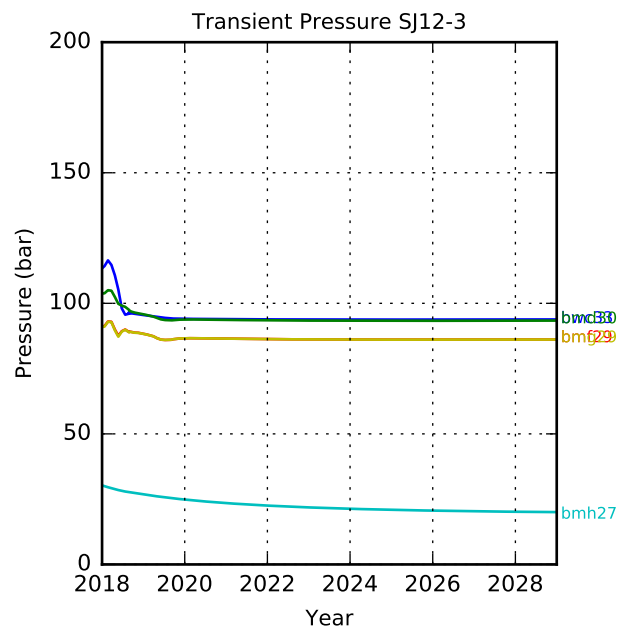
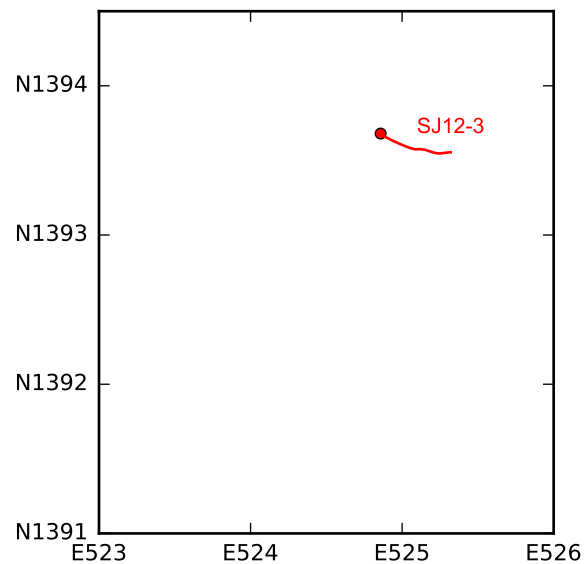


Feedzone Elevations

Feedzone	Elevation (masl)
-1500.0 masl	-1500.0 masl
-1300.0 masl	-1300.0 masl
-700.0 masl	-700.0 masl
-1500.0 masl	-1500.0 masl
-1100.0 masl	-1100.0 masl
-900.0 masl	-900.0 masl

— Total Mass Flow — Steam Flow

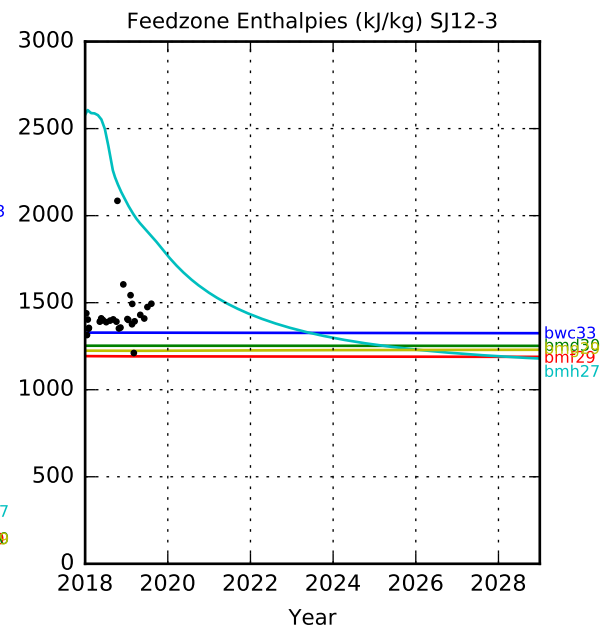
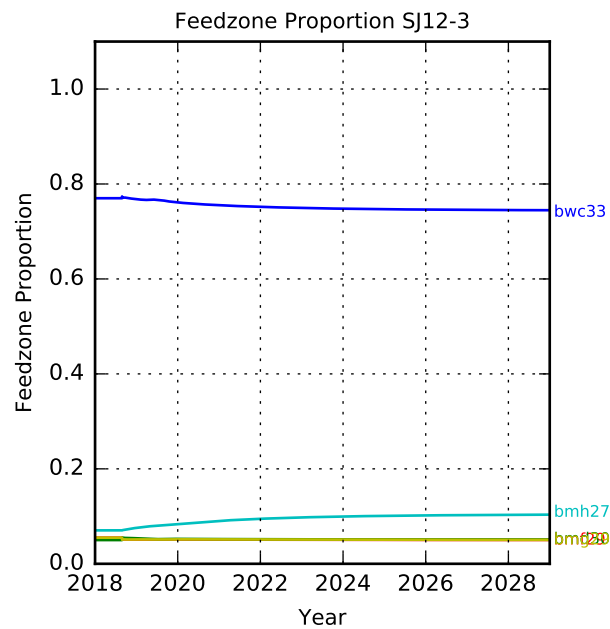
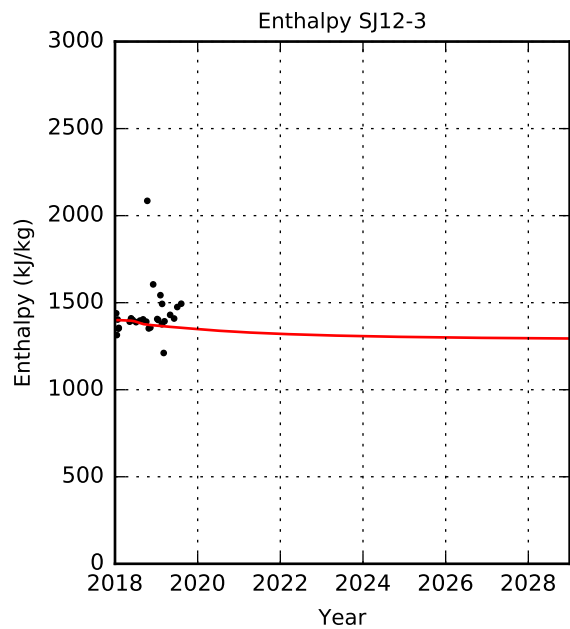


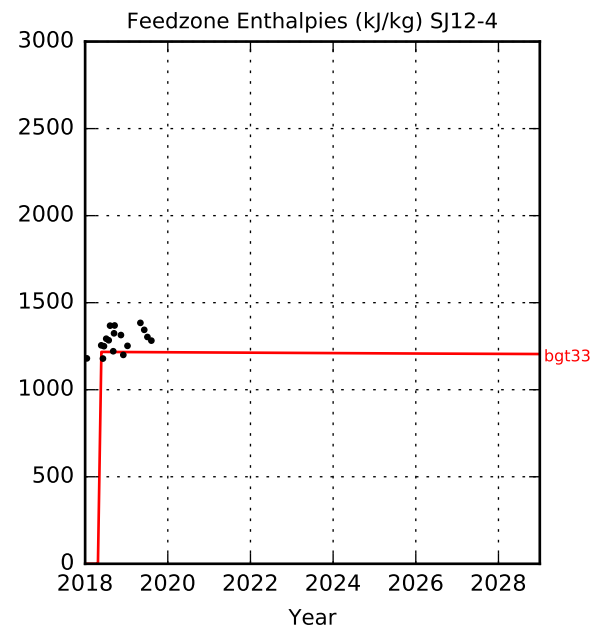
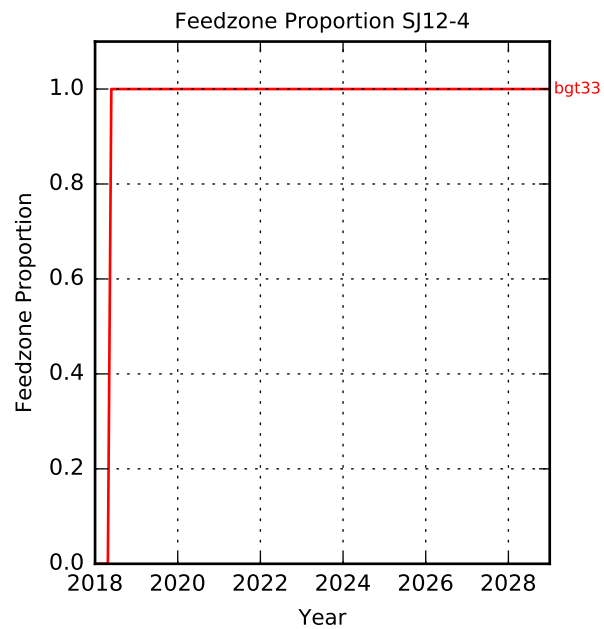
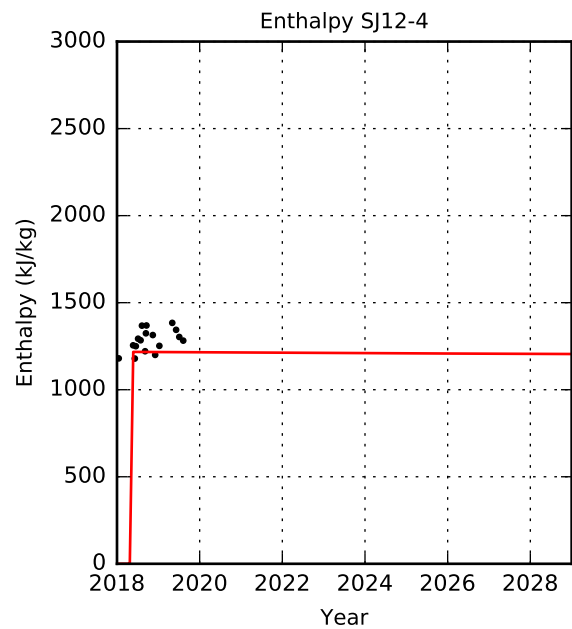
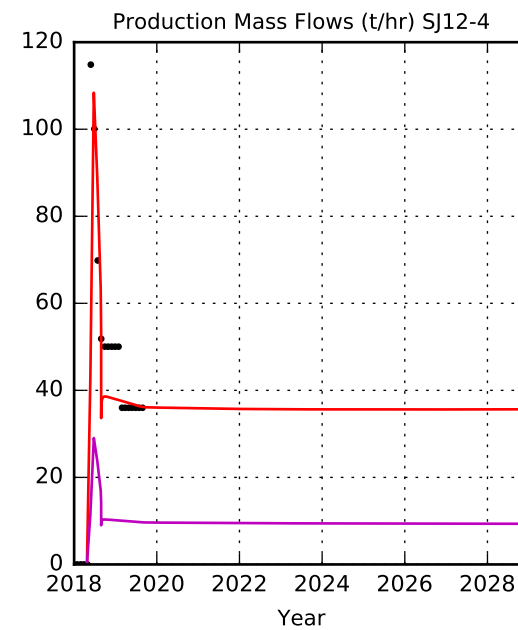
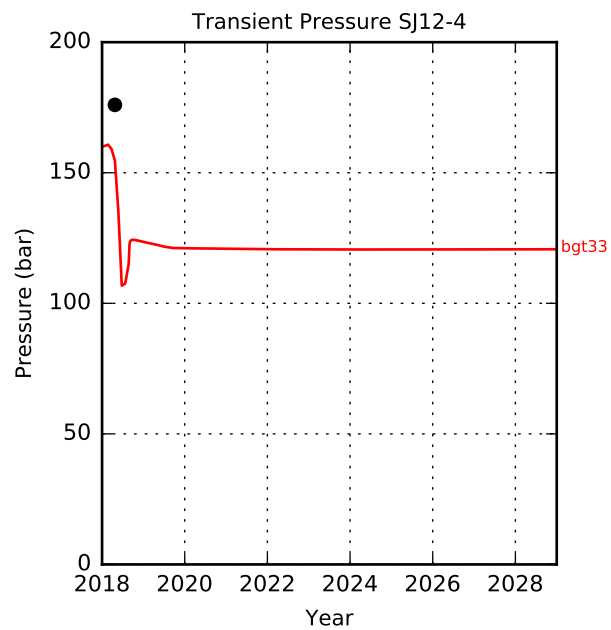
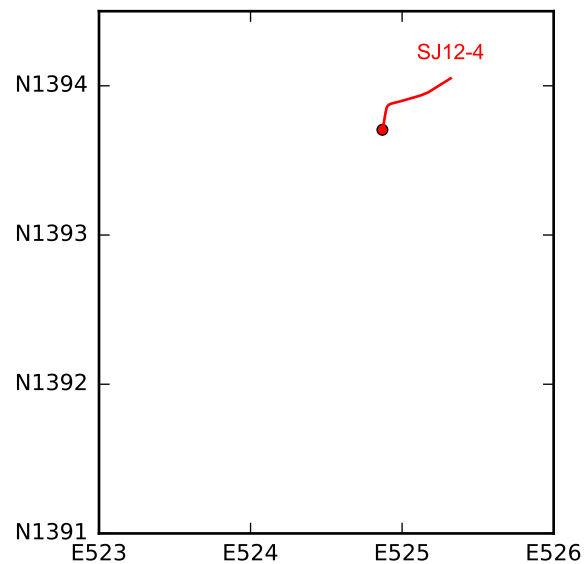


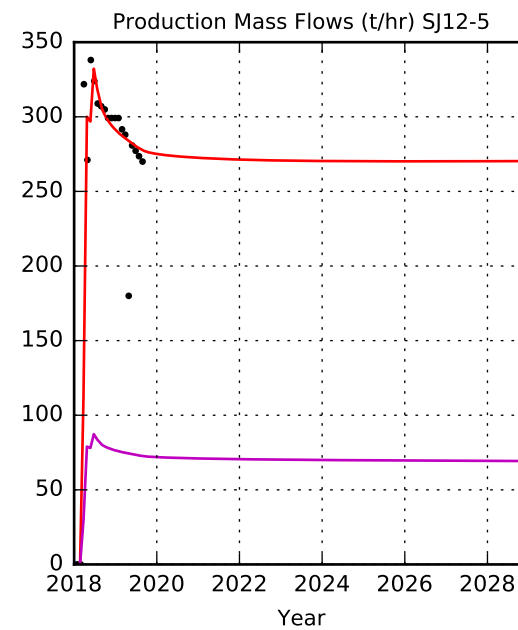
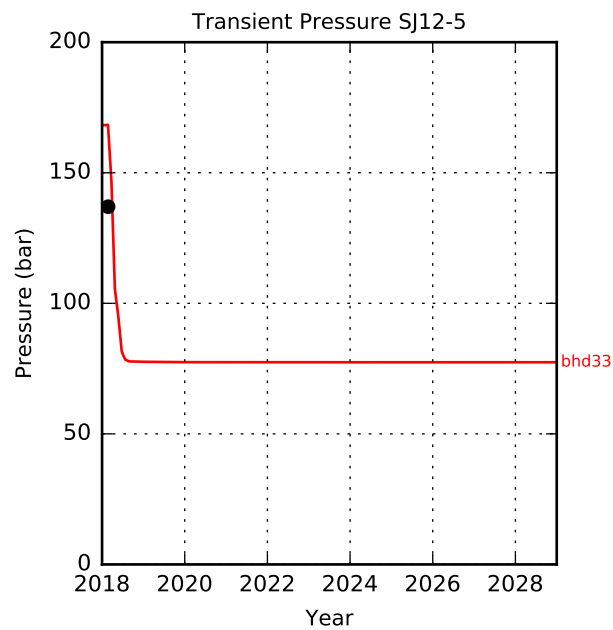
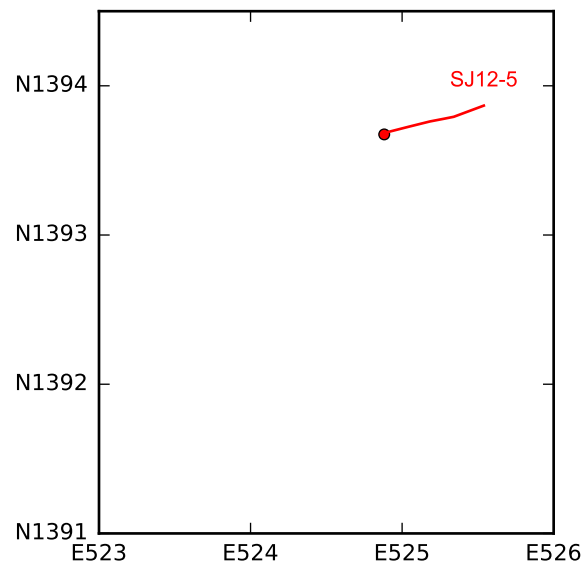
Feedzone Elevations

- 1100.0 masl
- 2000.0 masl
- 1300.0 masl
- 700.0 masl
- 1100.0 masl

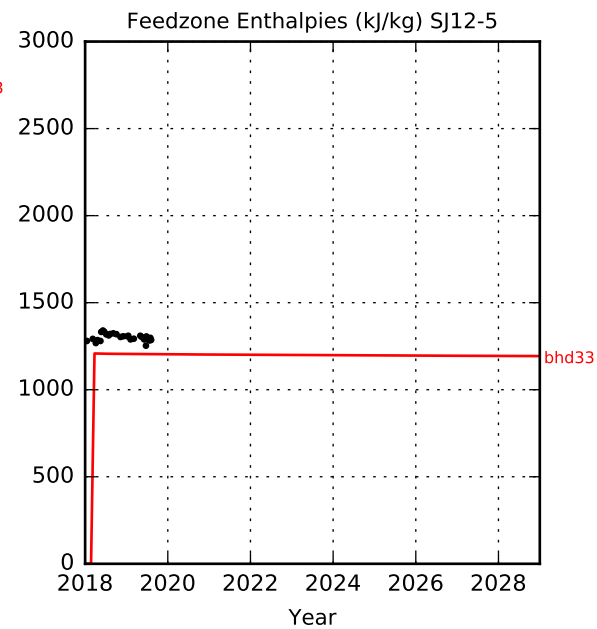
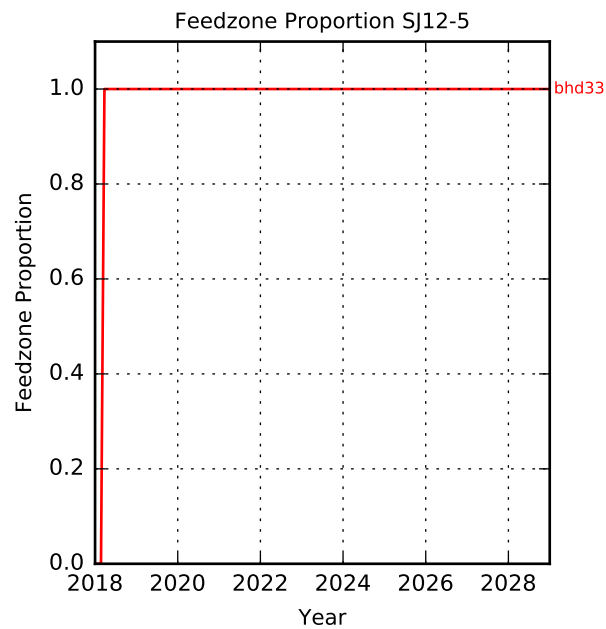
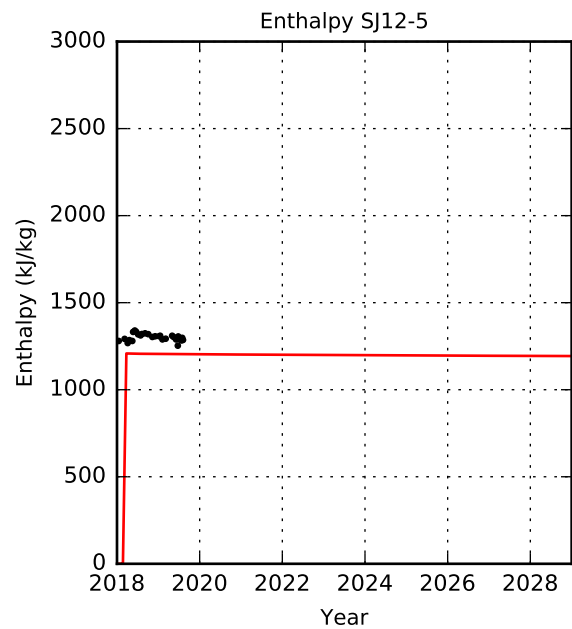
— Total Mass Flow — Steam Flow

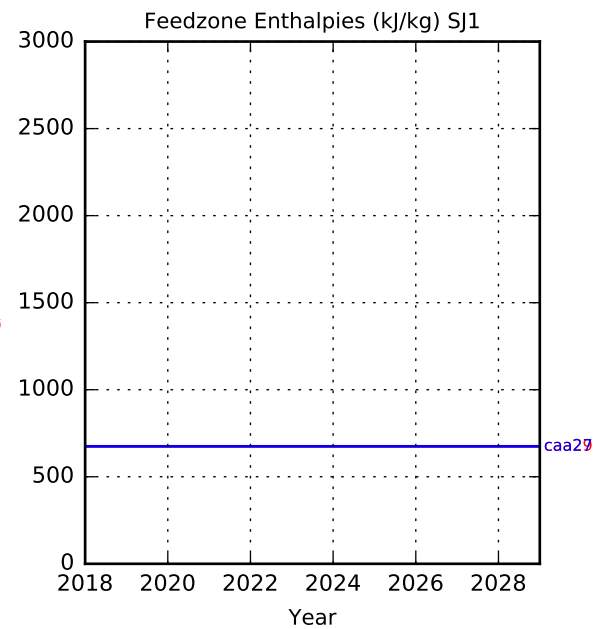
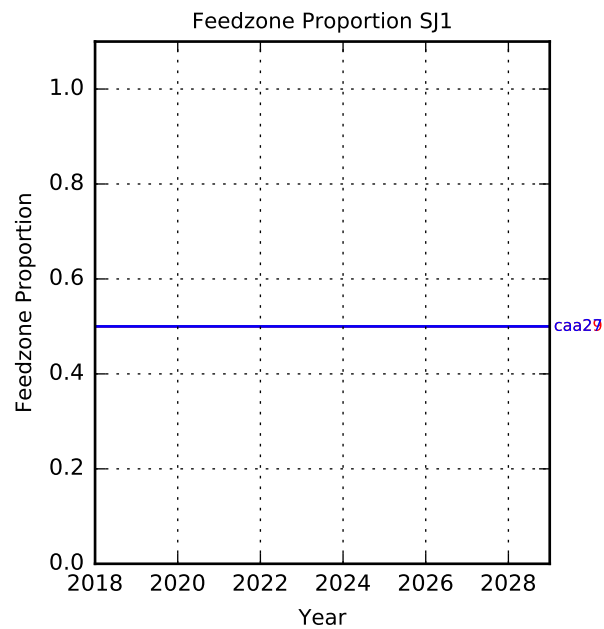
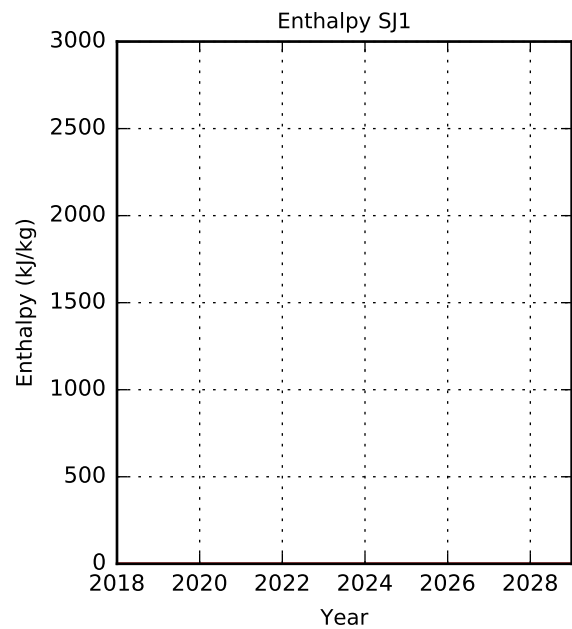
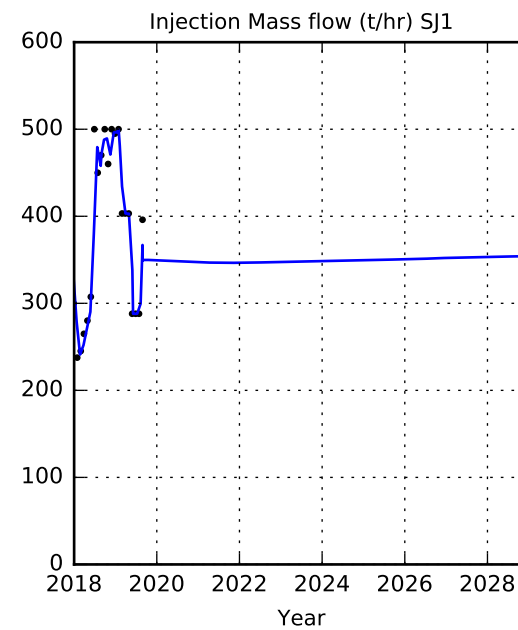
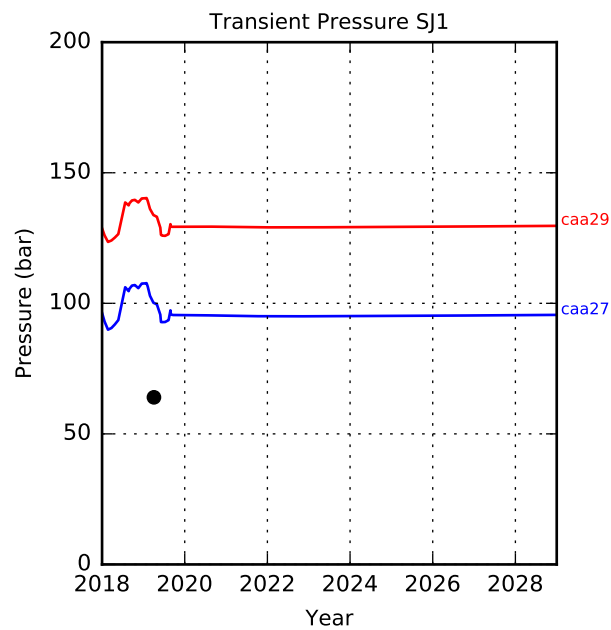
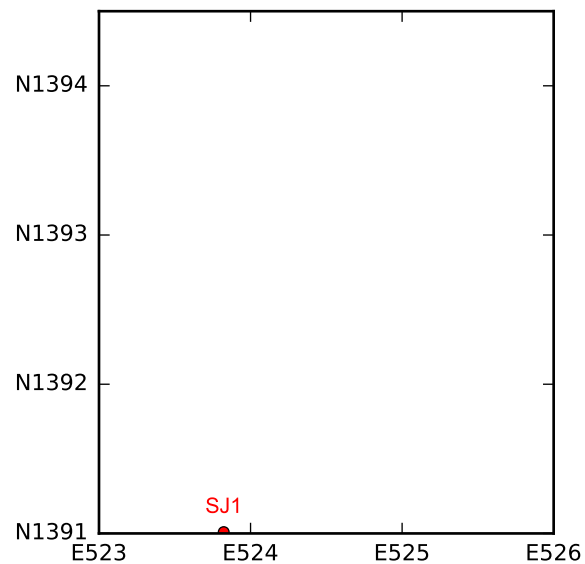


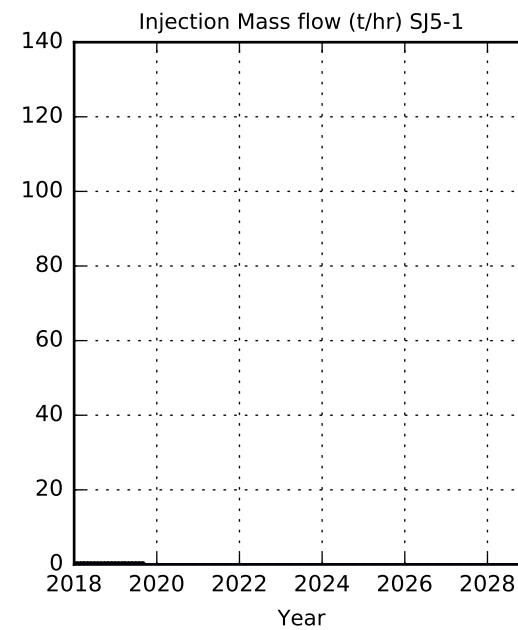
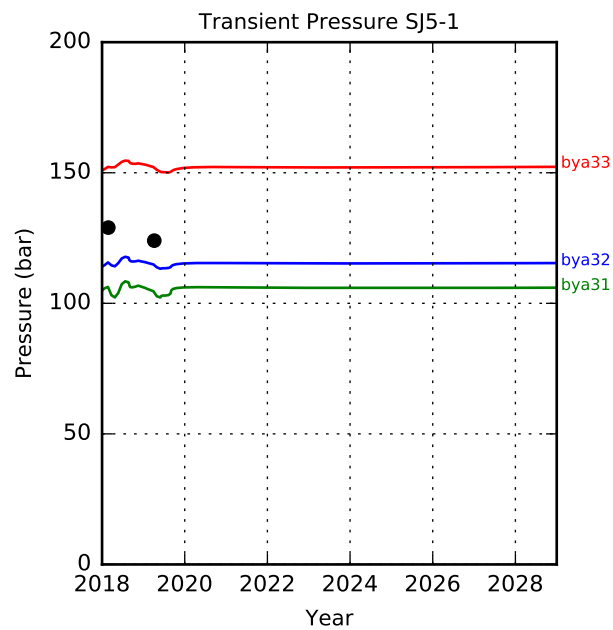
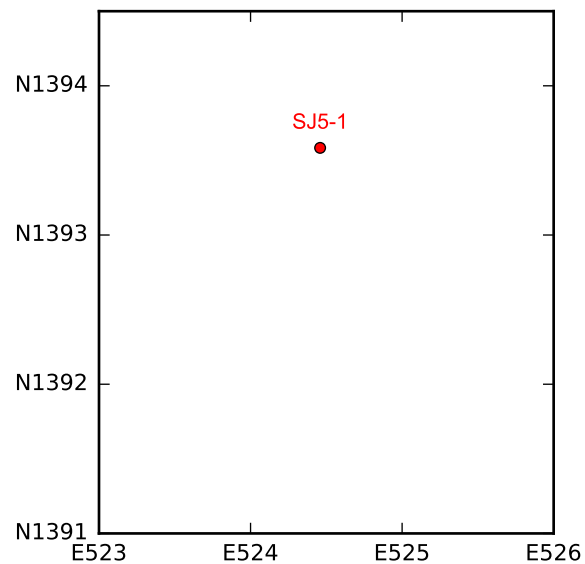




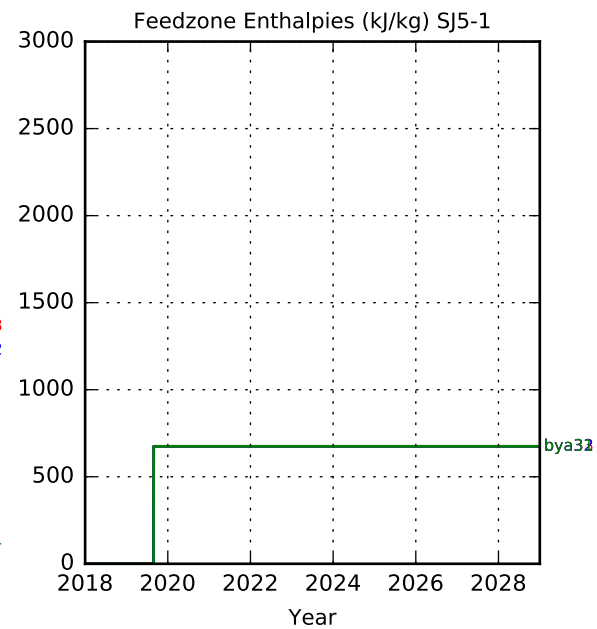
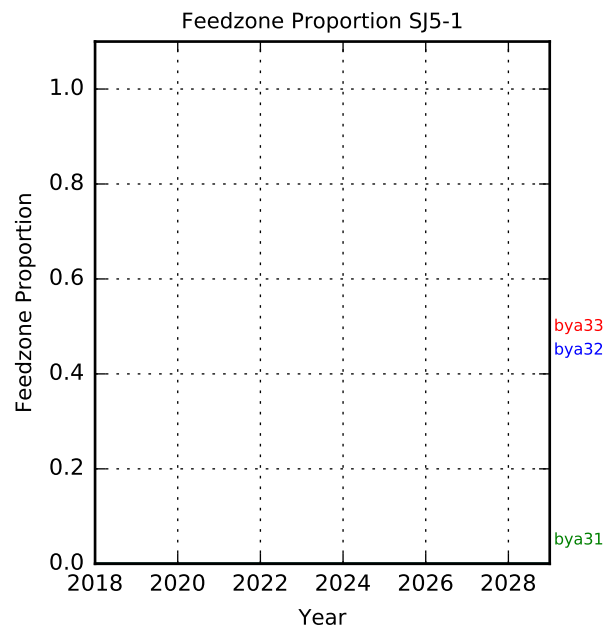
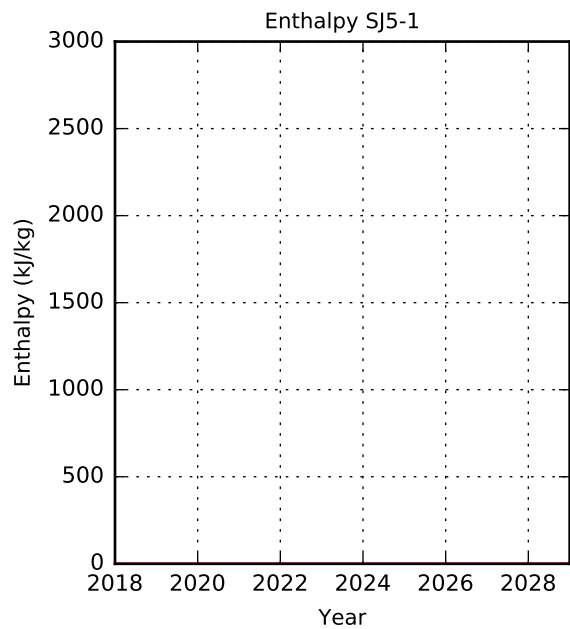
— Total Mass Flow — Steam Flow

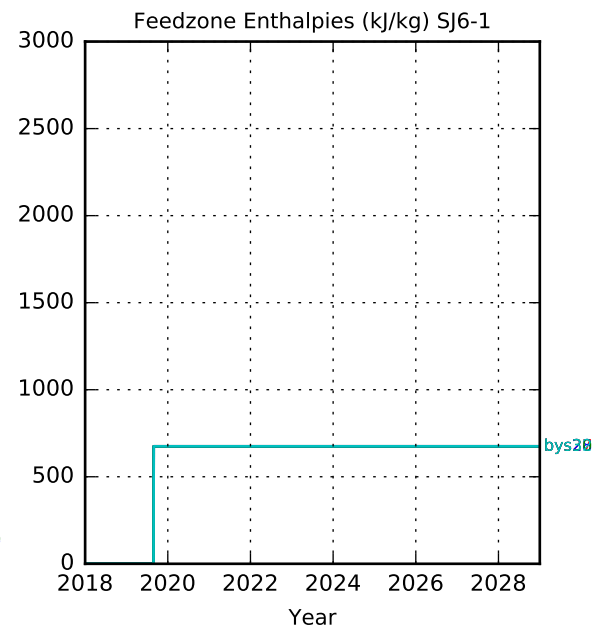
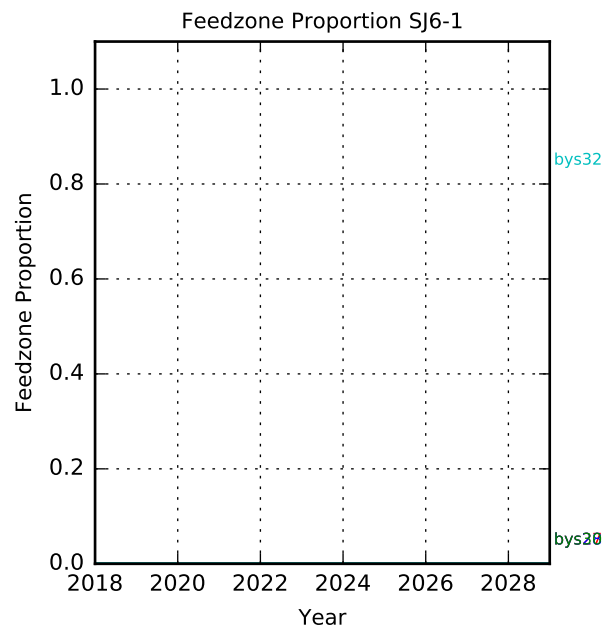
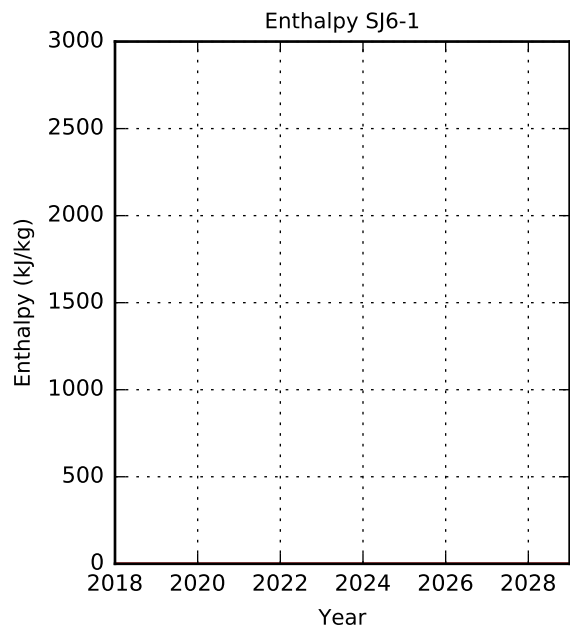
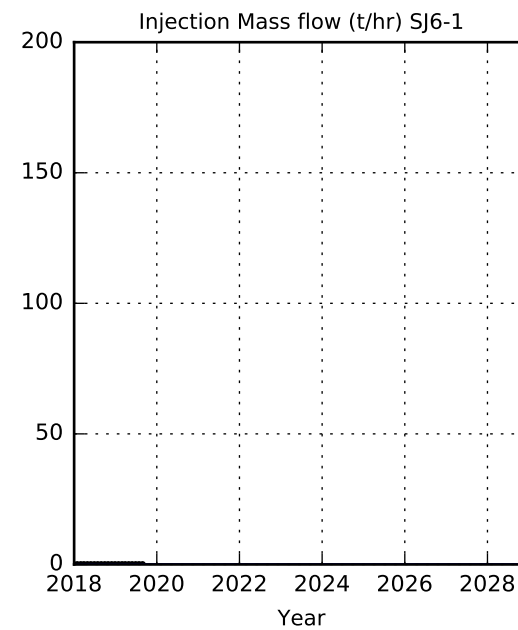
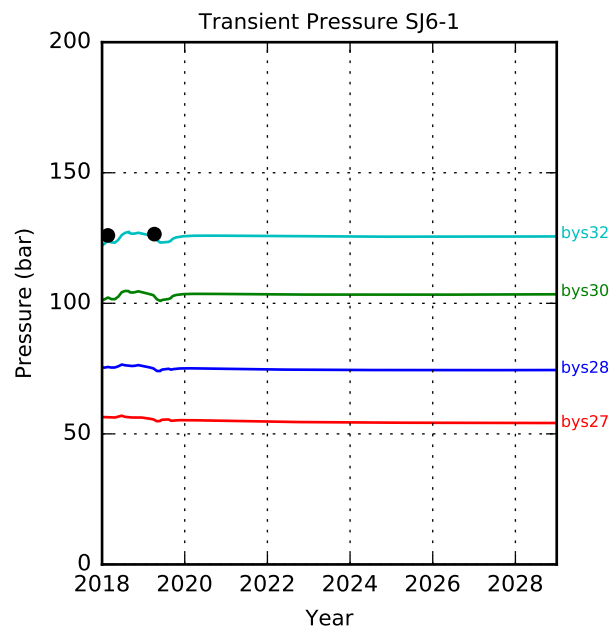
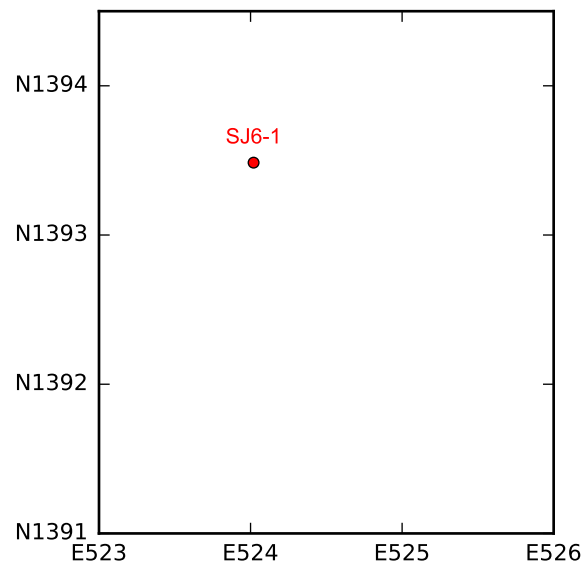


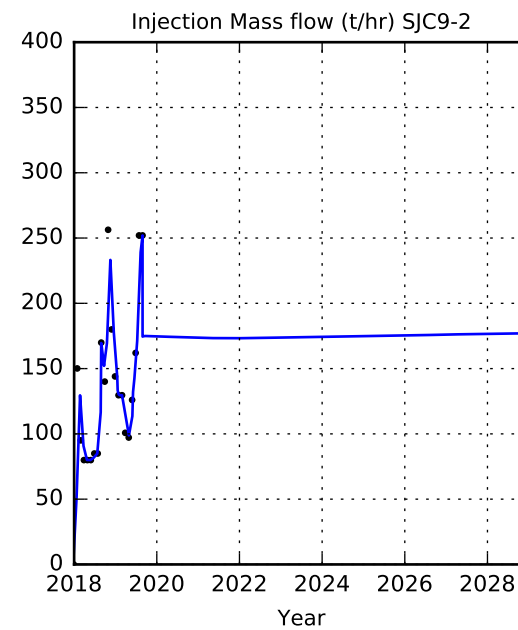
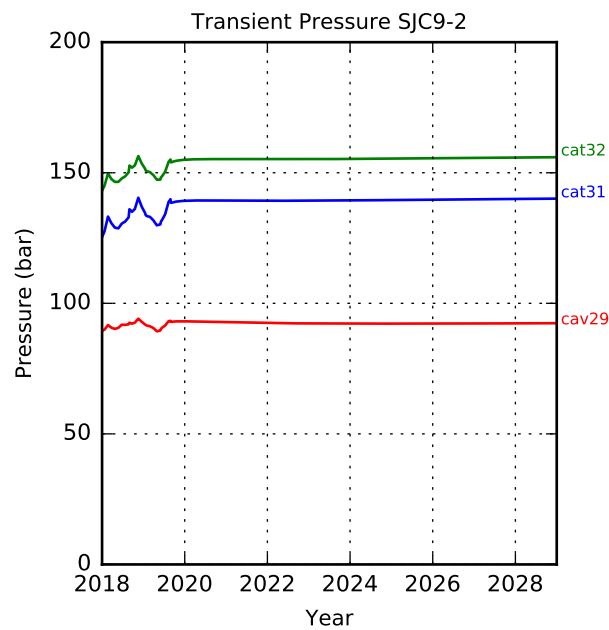
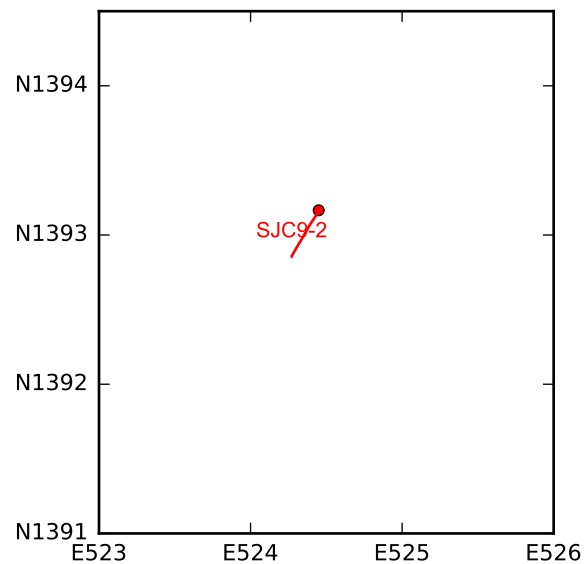




Feedzone Elevations
-2000.0 masl -1700.0 masl -1500.0 masl

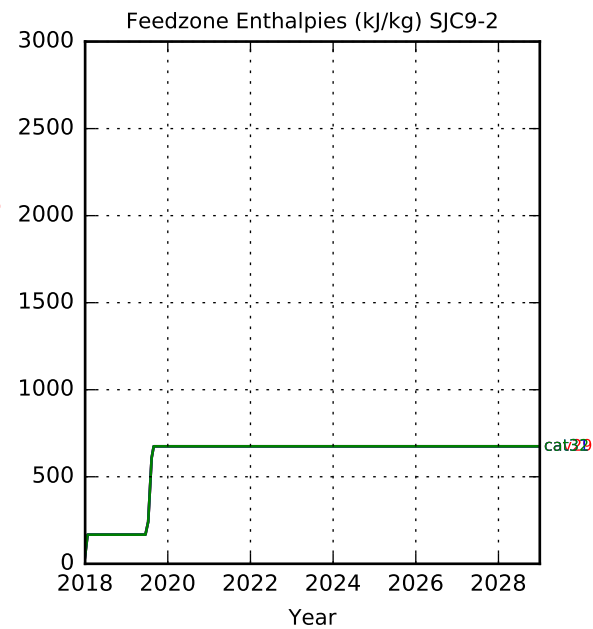
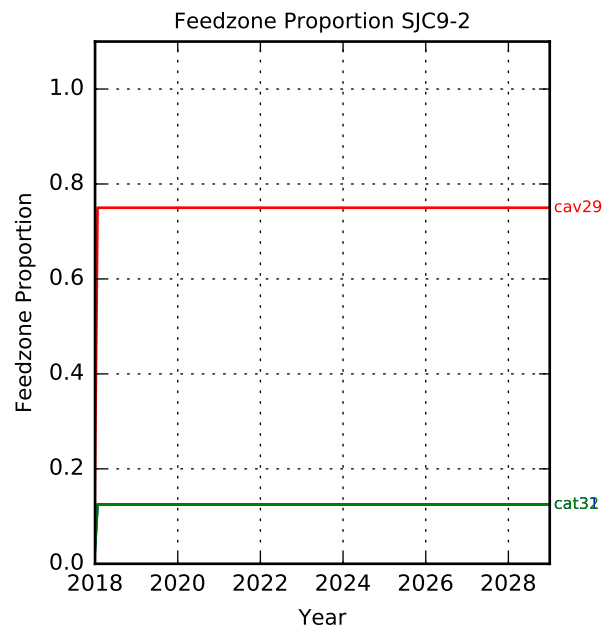
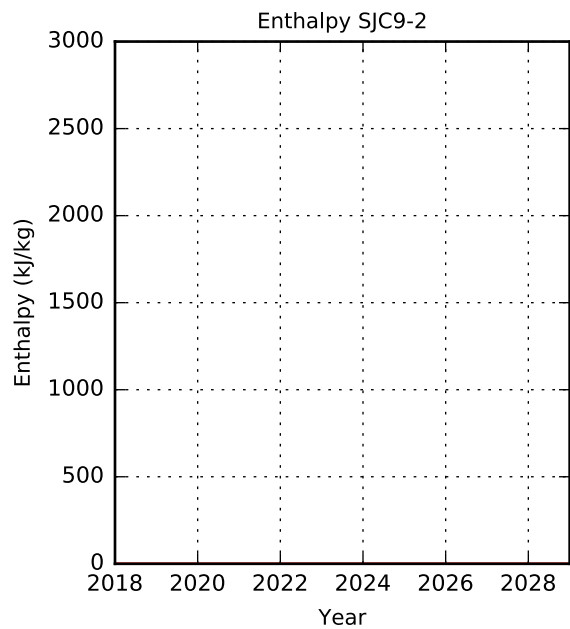


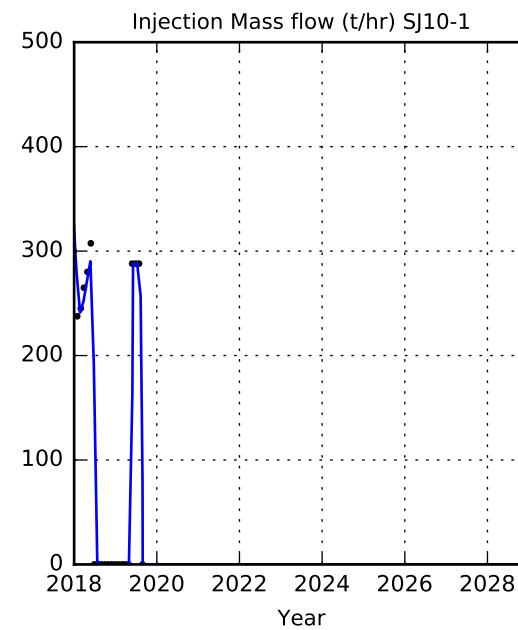
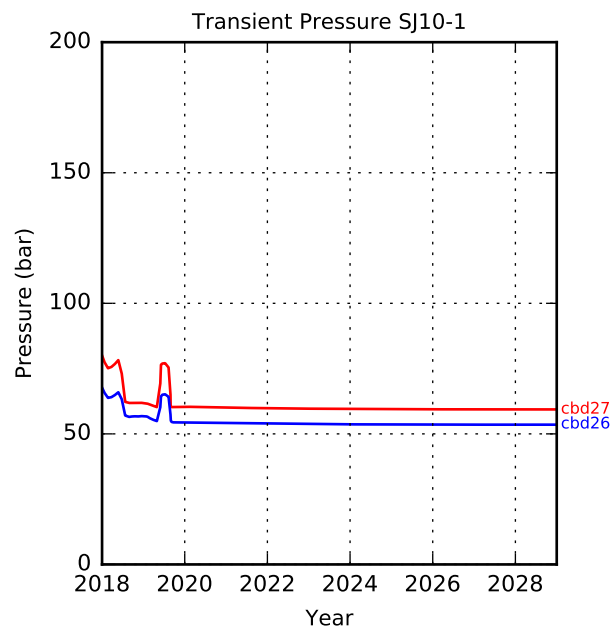
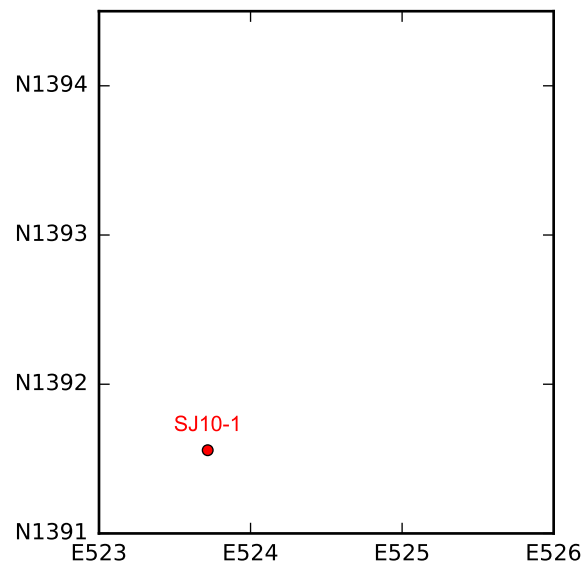




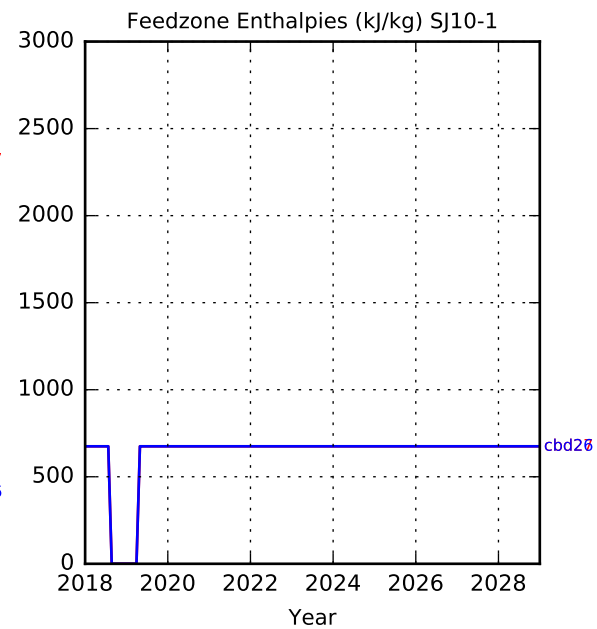
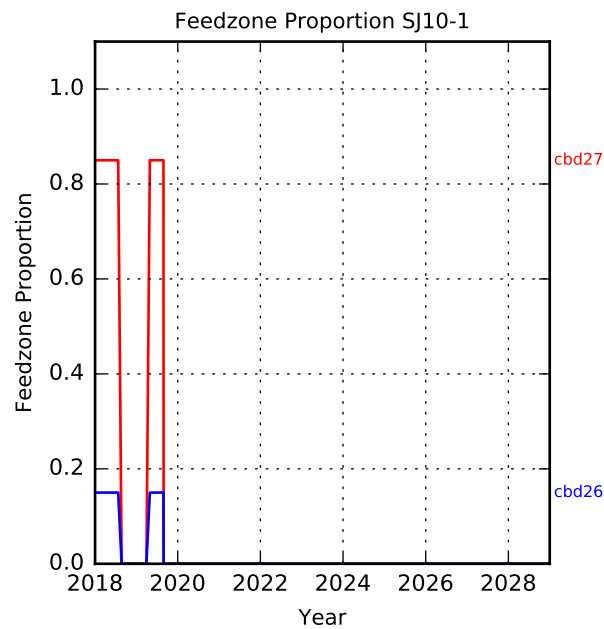
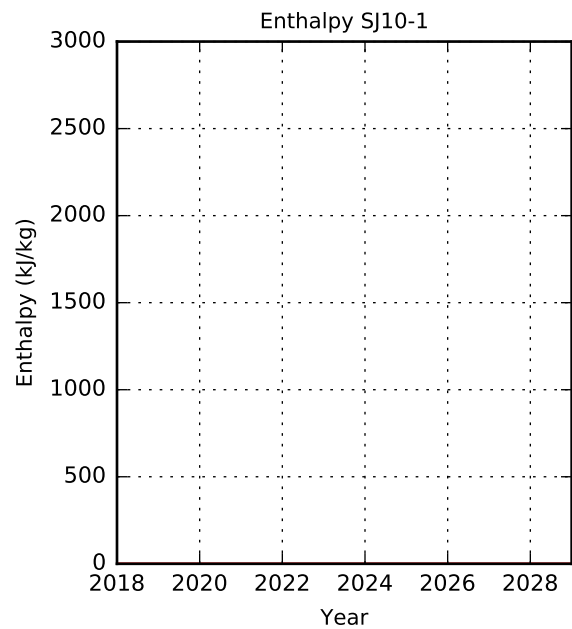
Feedzone Elevations

-1100.0 masl -1500.0 masl -1700.0 masl

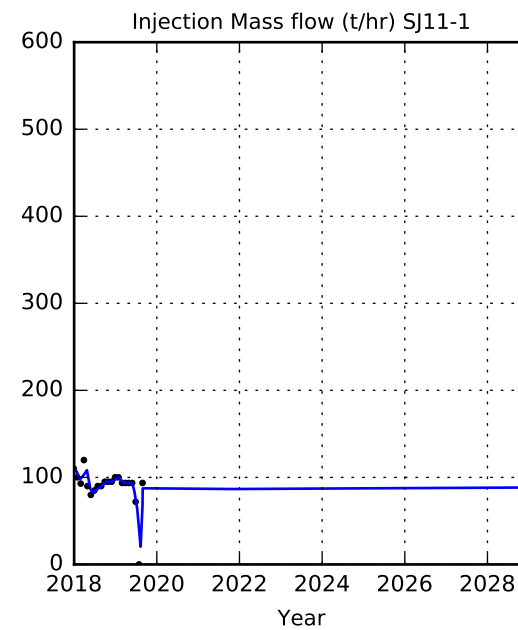
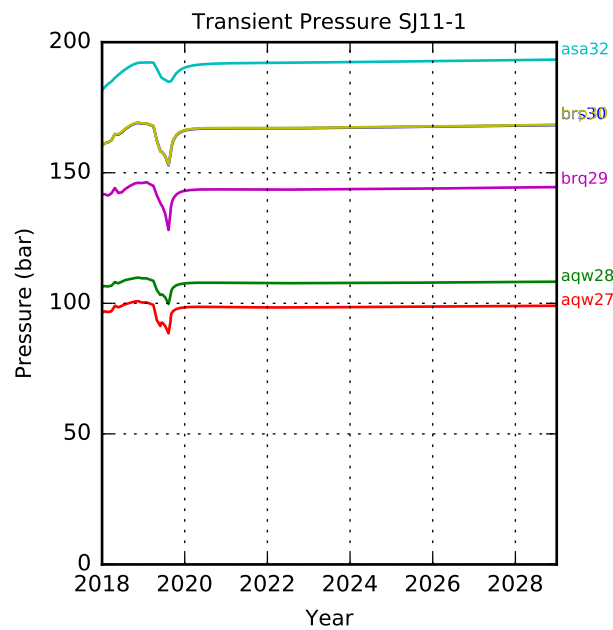
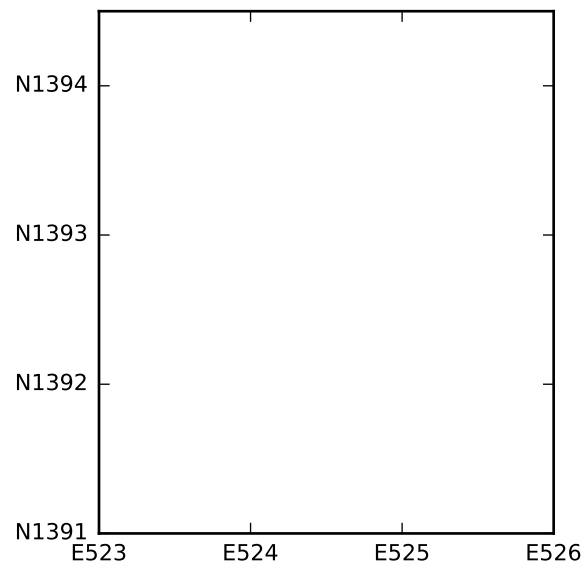




Feedzone Elevations
-700.0 masl -525.0 masl

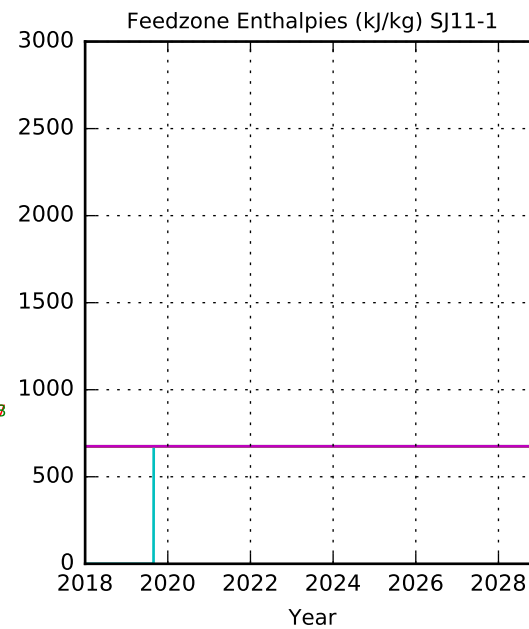
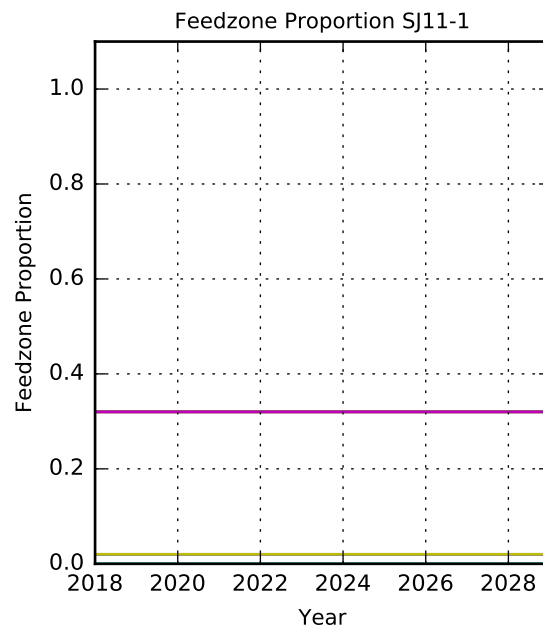
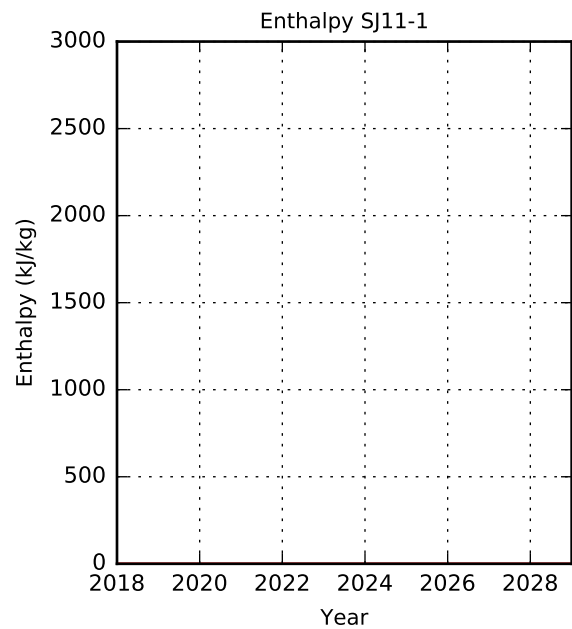


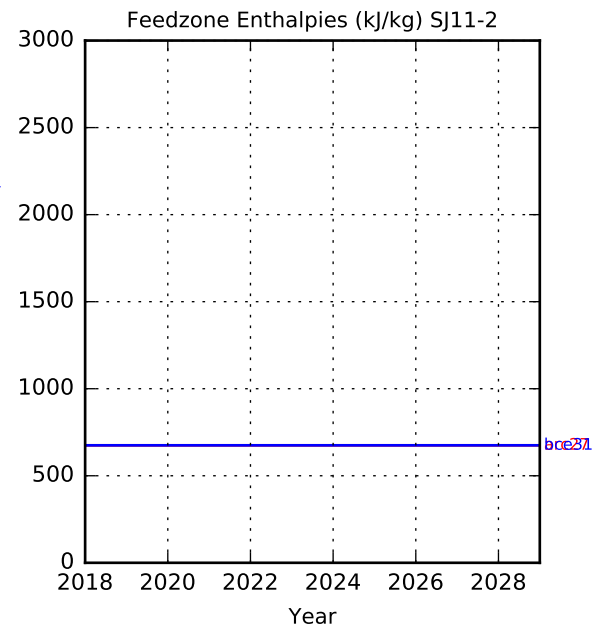
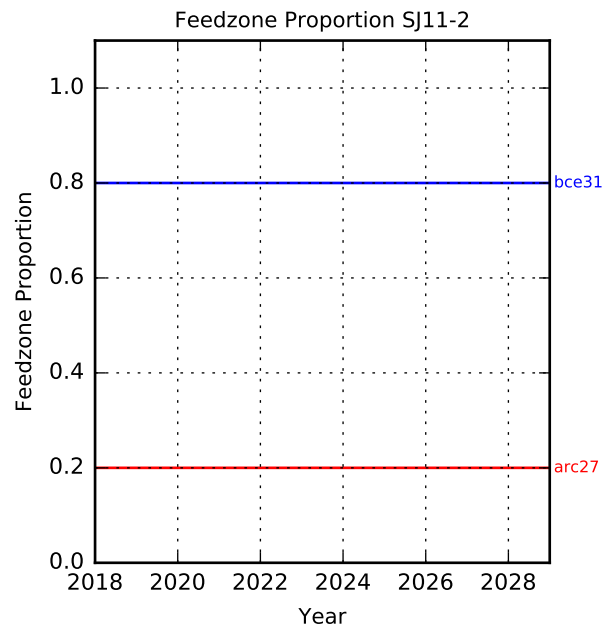
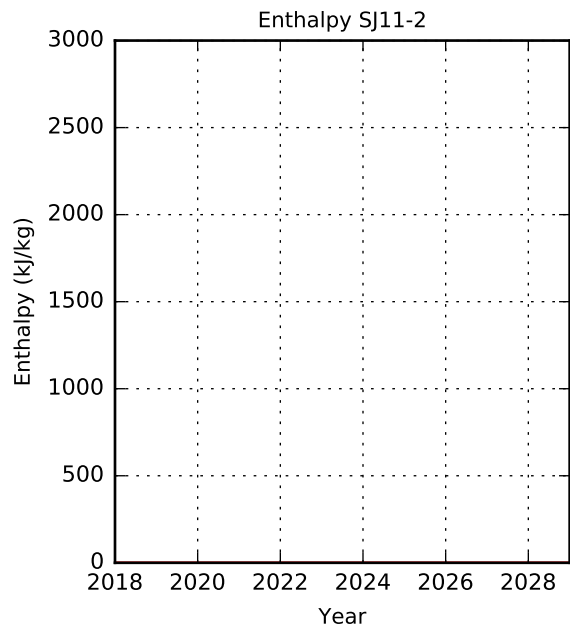
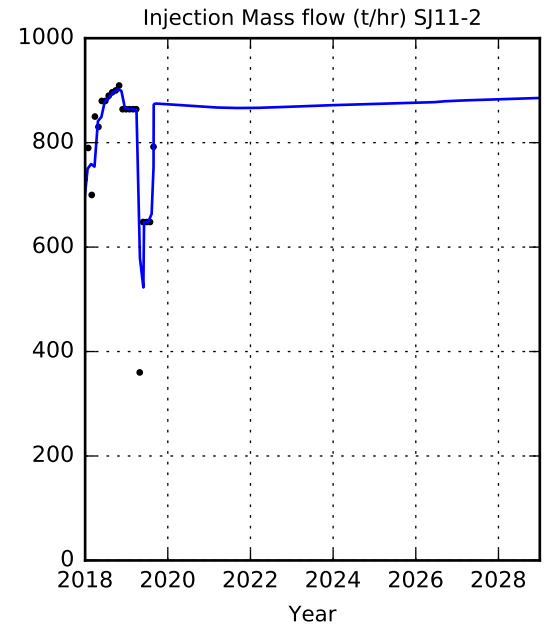
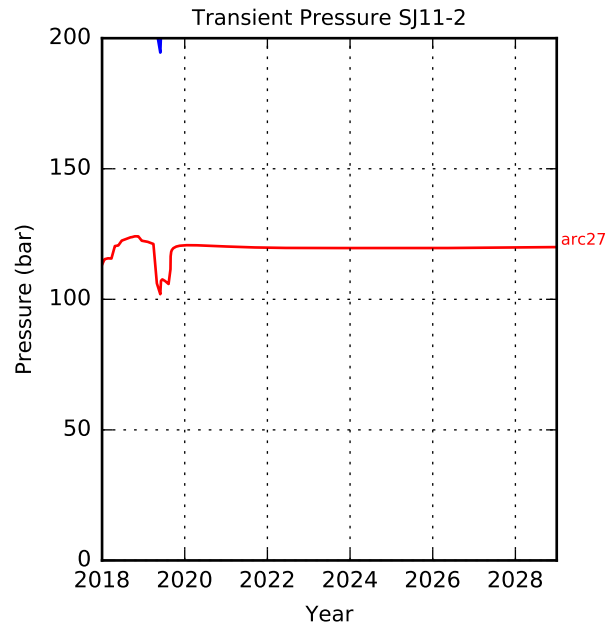
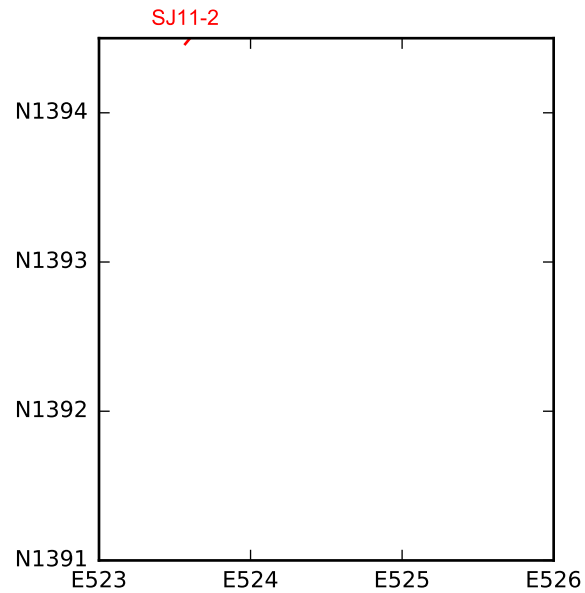
SJ11-1

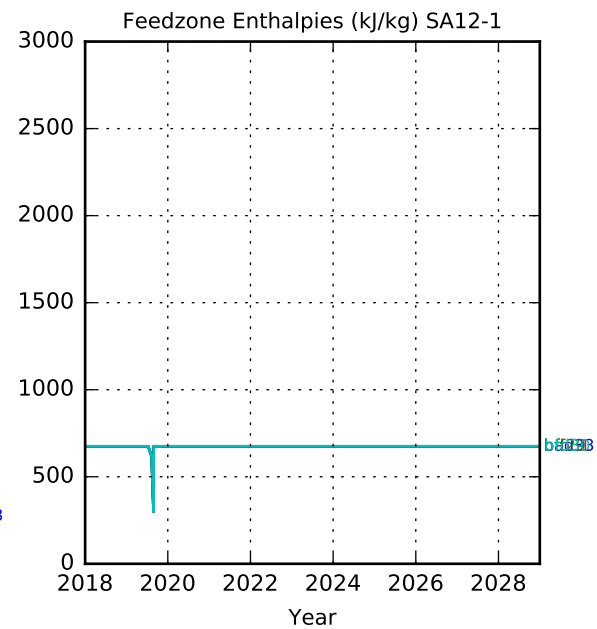
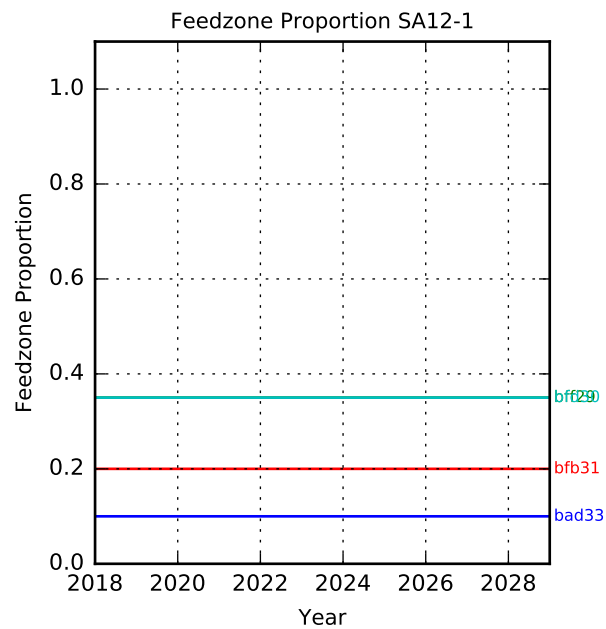
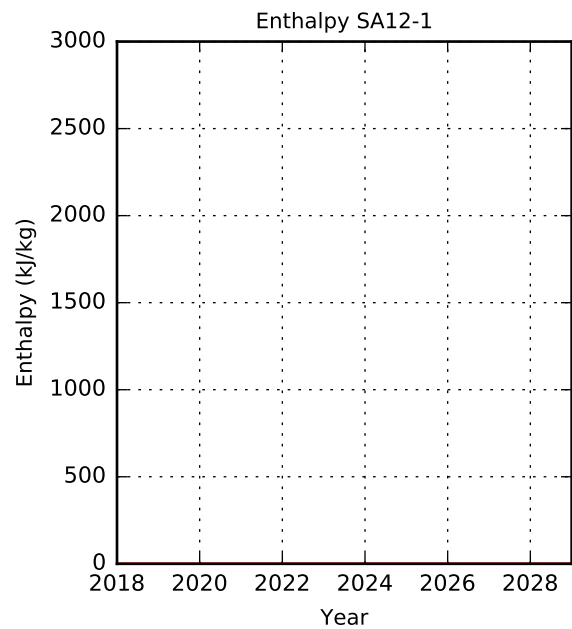
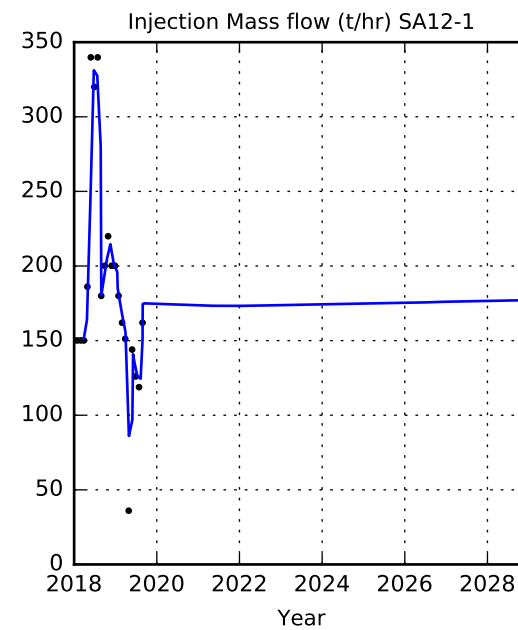
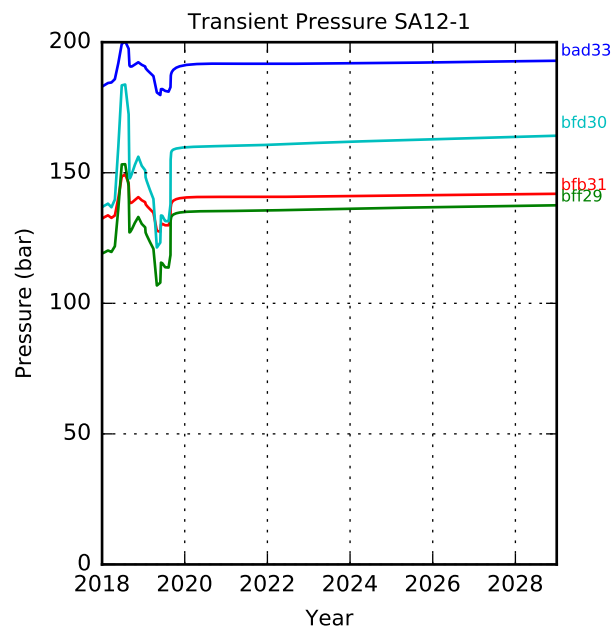
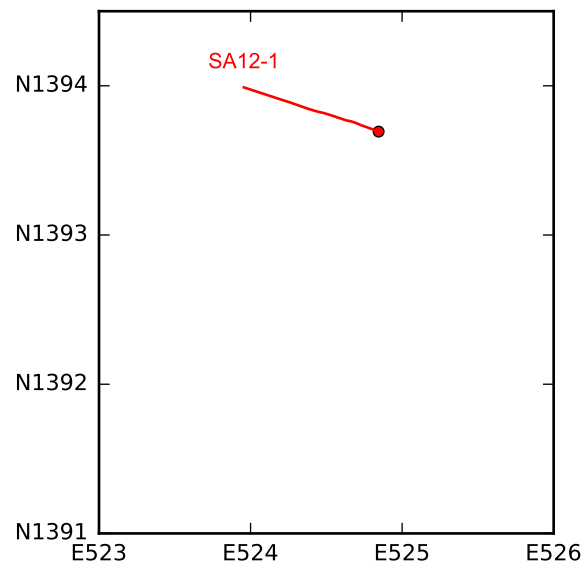


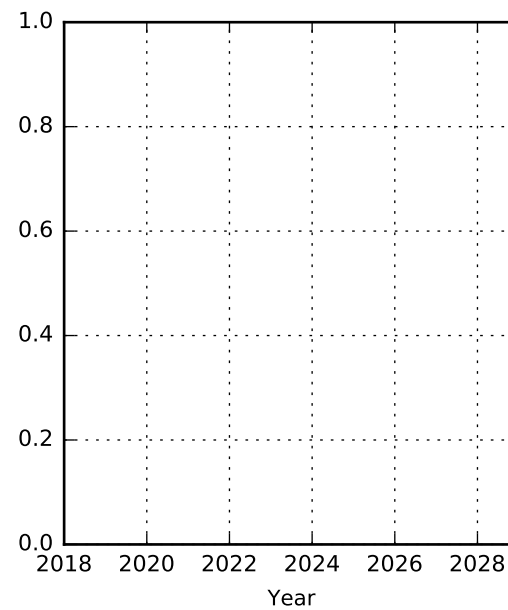
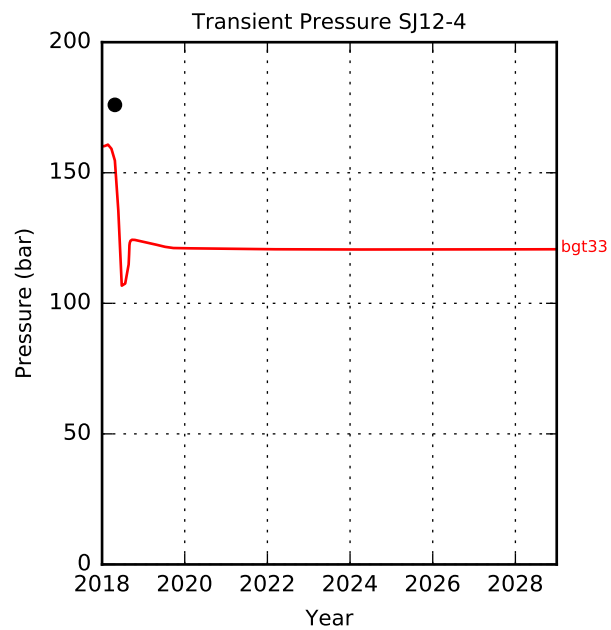
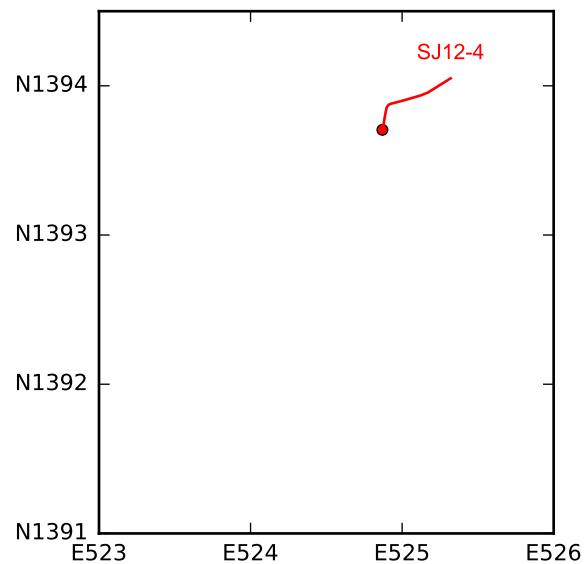
Feedzone Elevations

-700.0 masl -1300.0 masl -900.0 masl
-1700.0 masl -1300.0 masl -1100.0 masl



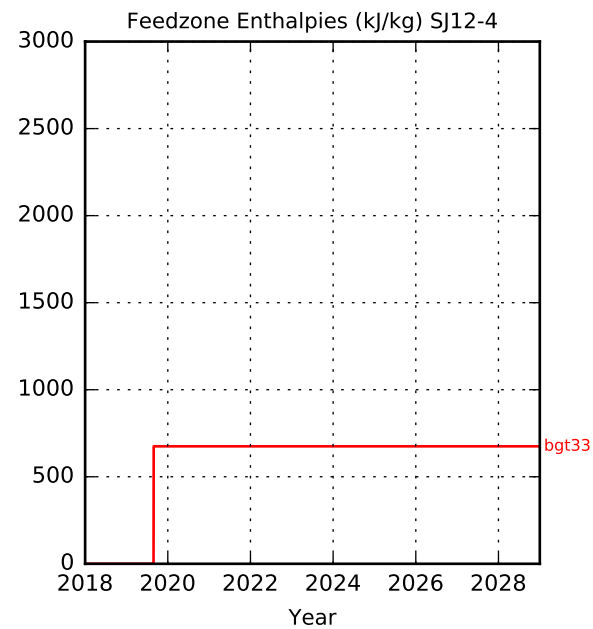
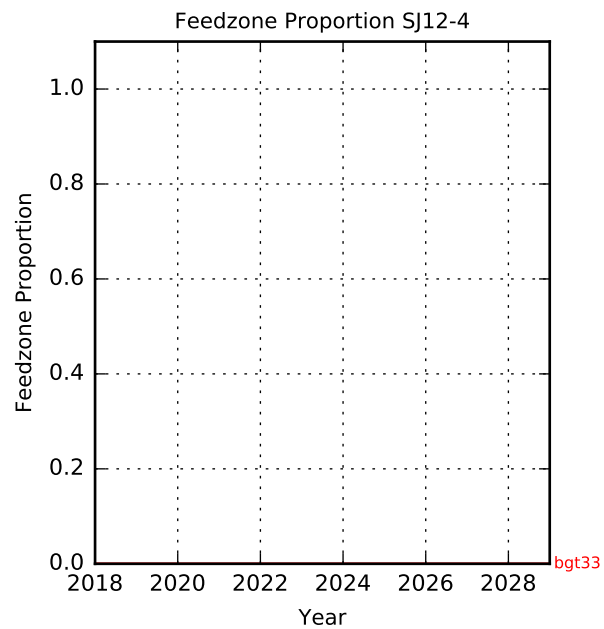
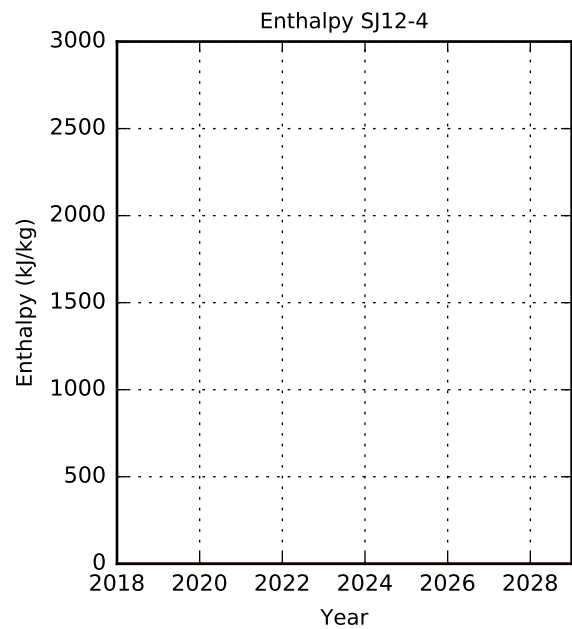


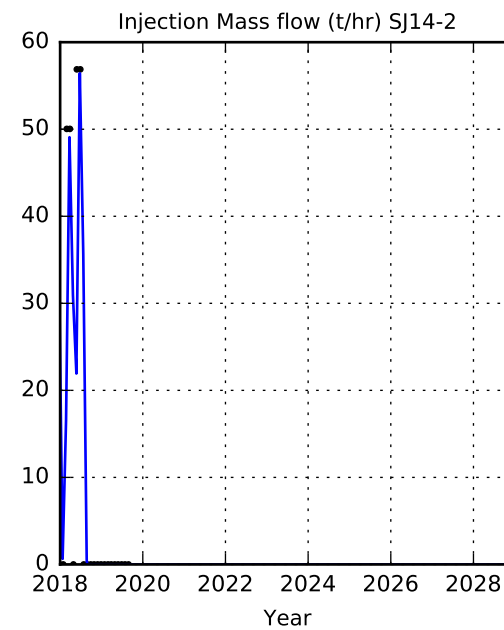
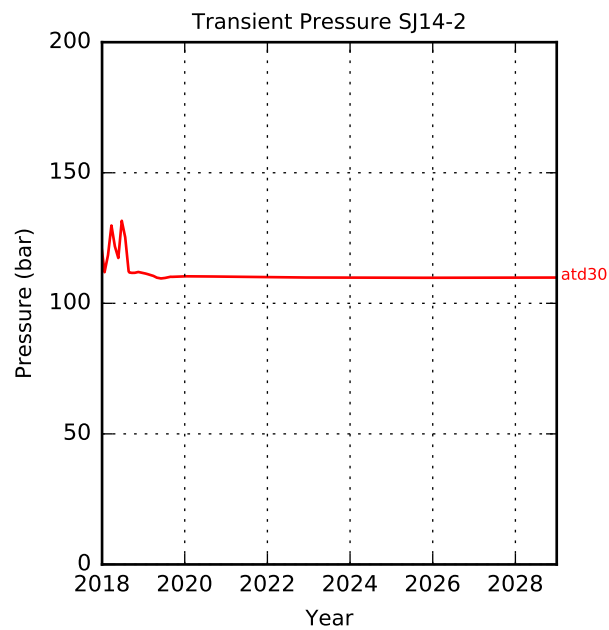
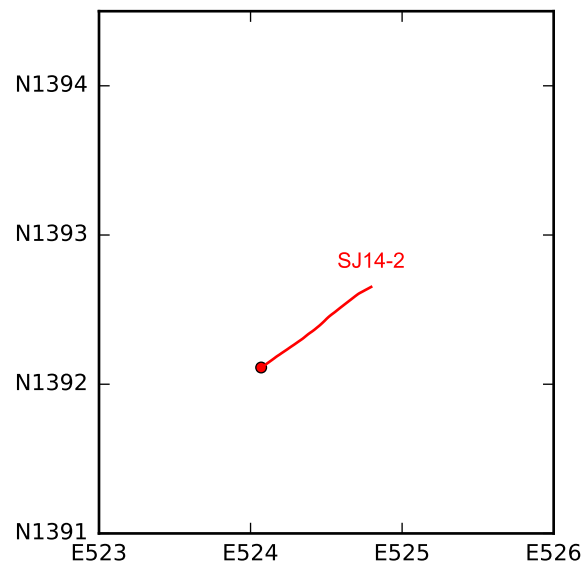




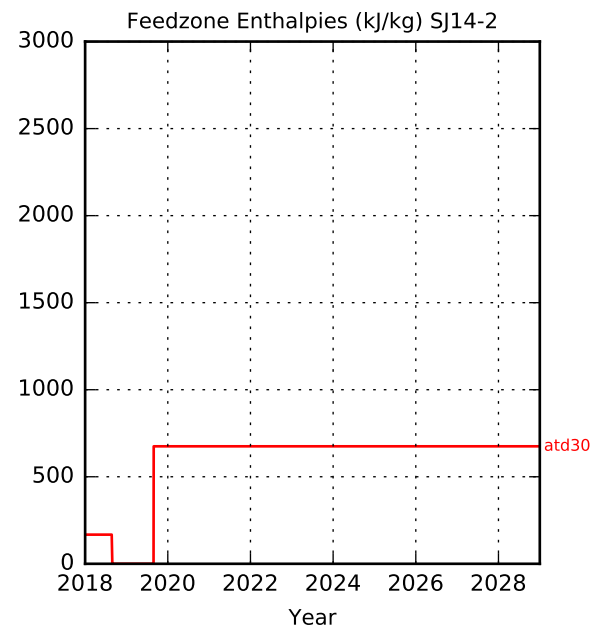
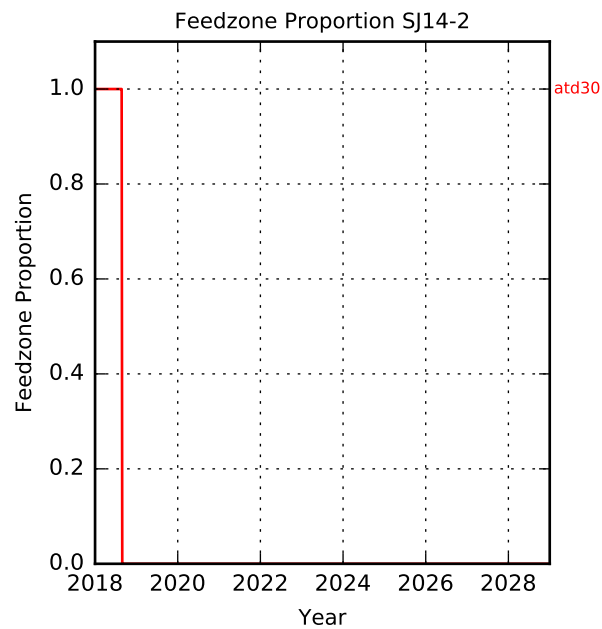
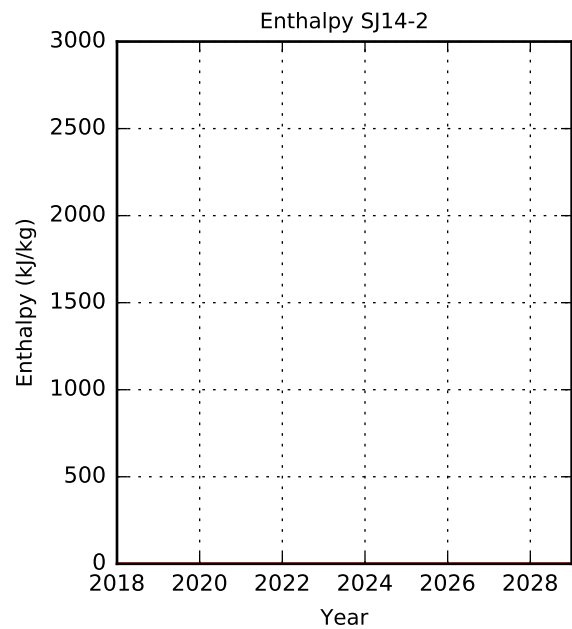
Feedzone Elevations

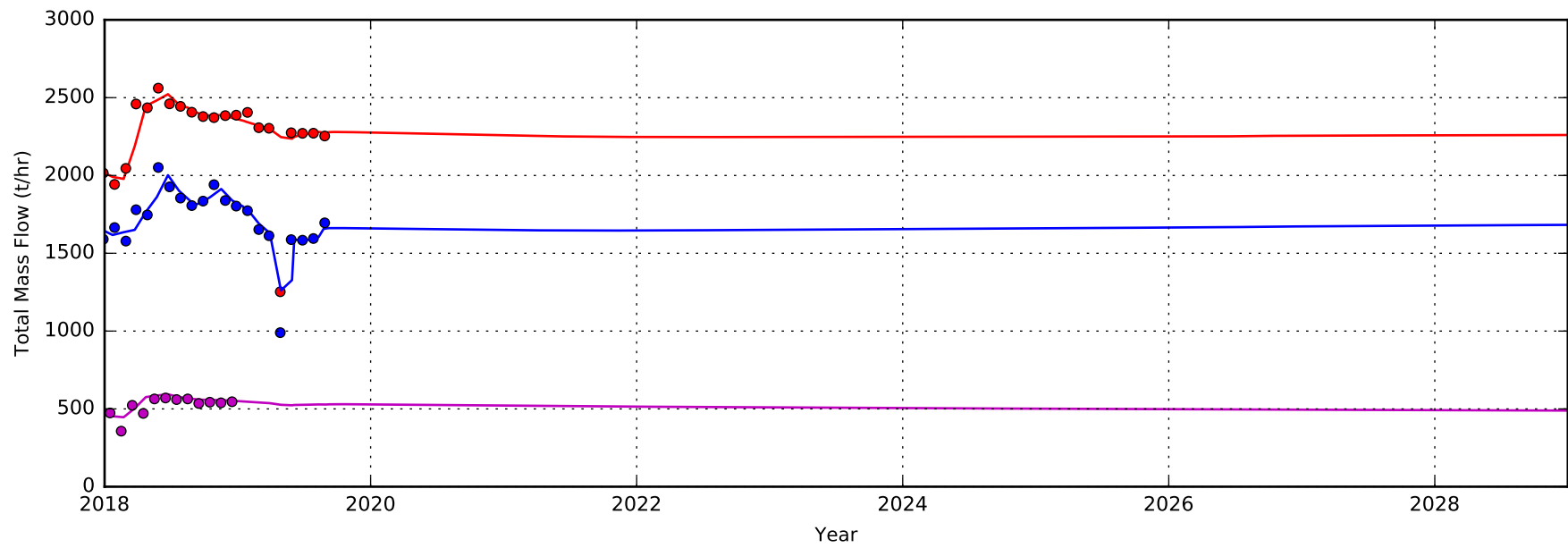
-2000.0 masl



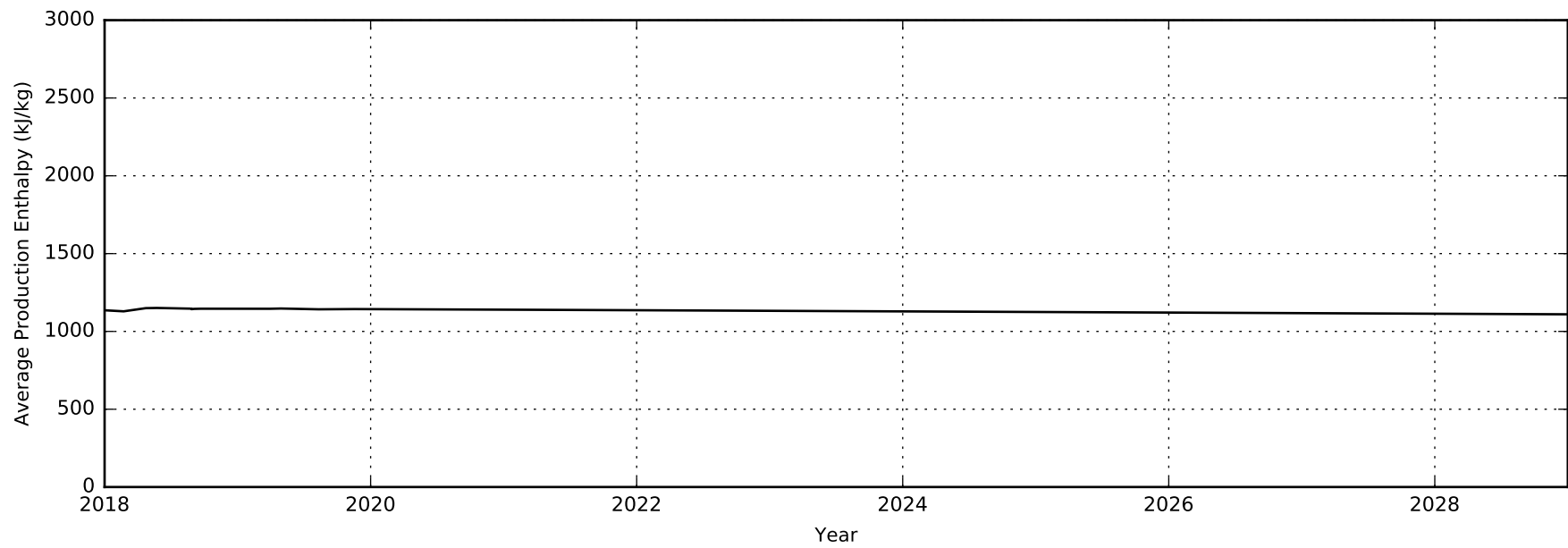


Feedzone Elevations
-1300.0 masl

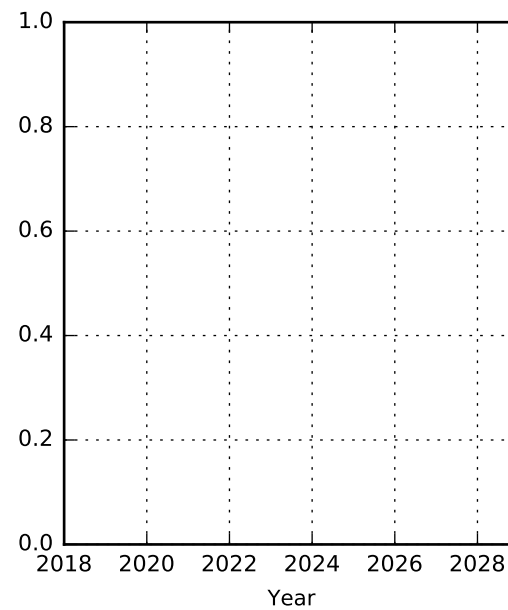
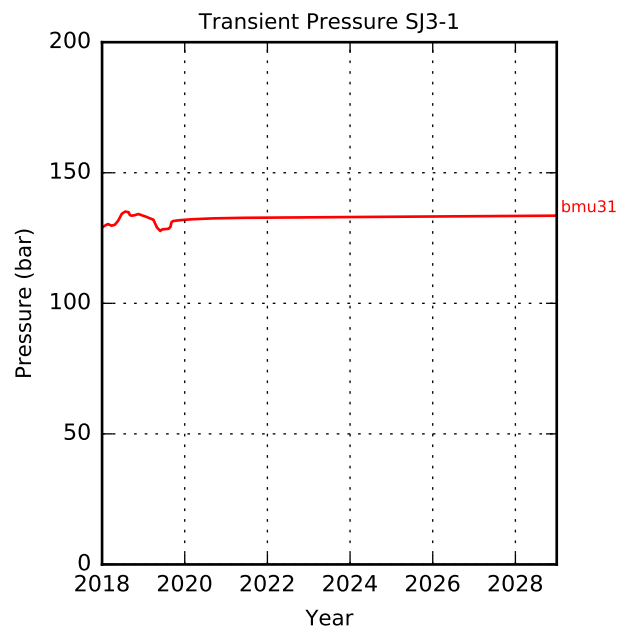
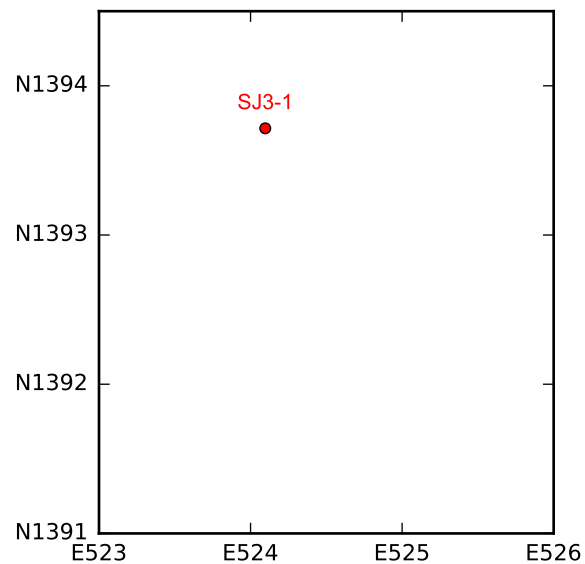




— Total Production — Total Steam — Total Reinjection

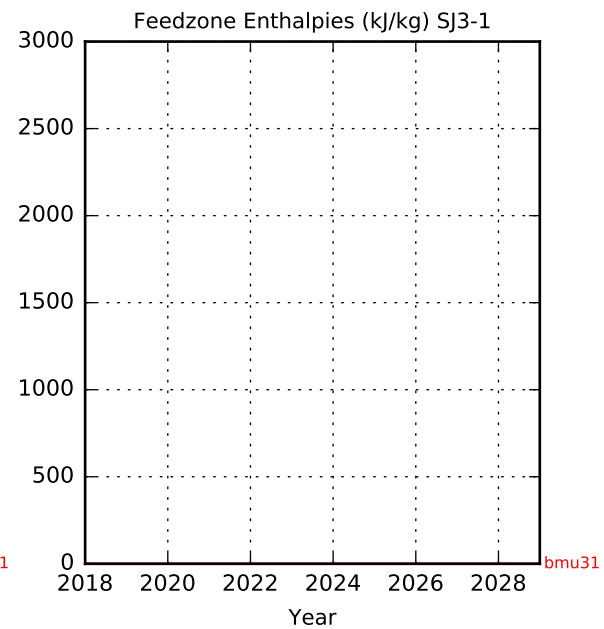
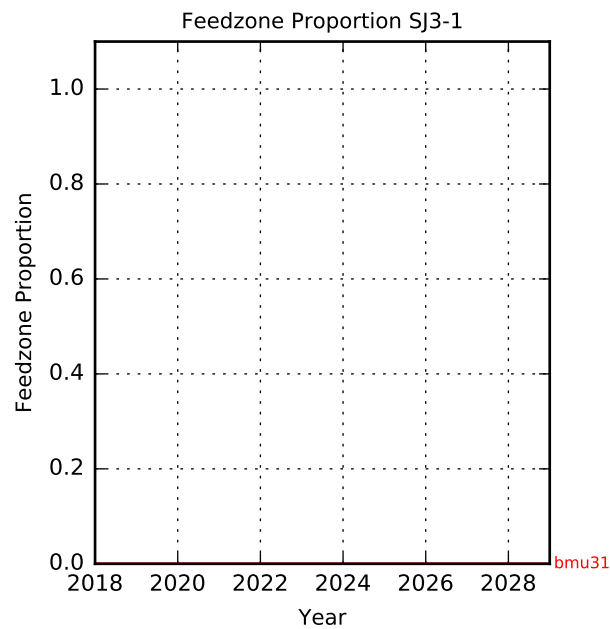
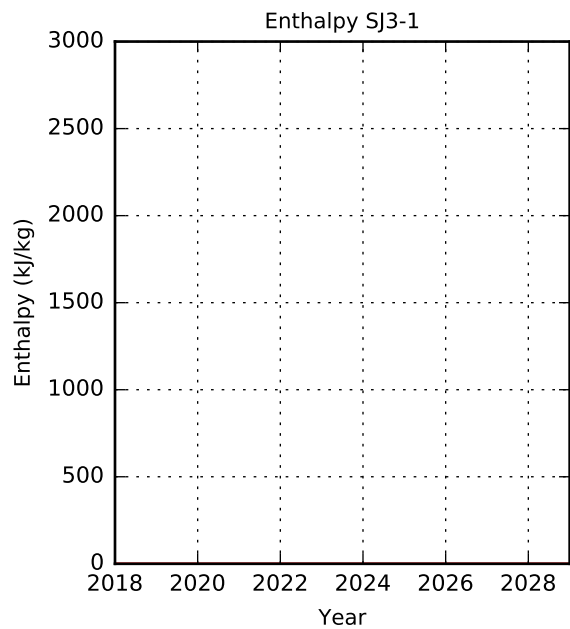


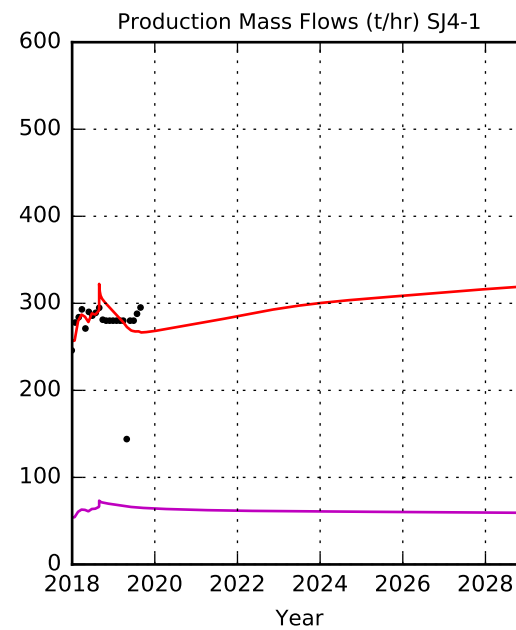
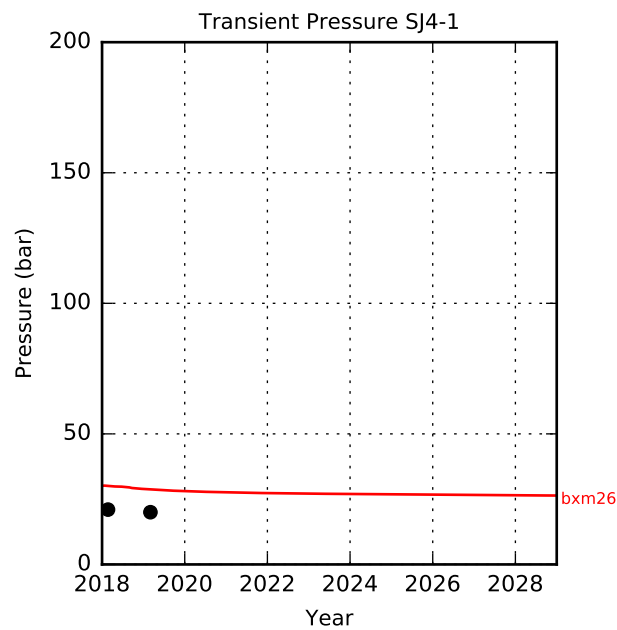
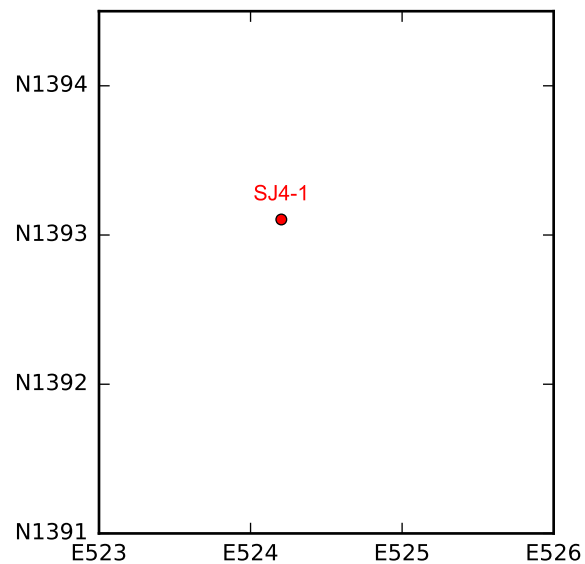
Appendix D. Future Scenario 002 Results



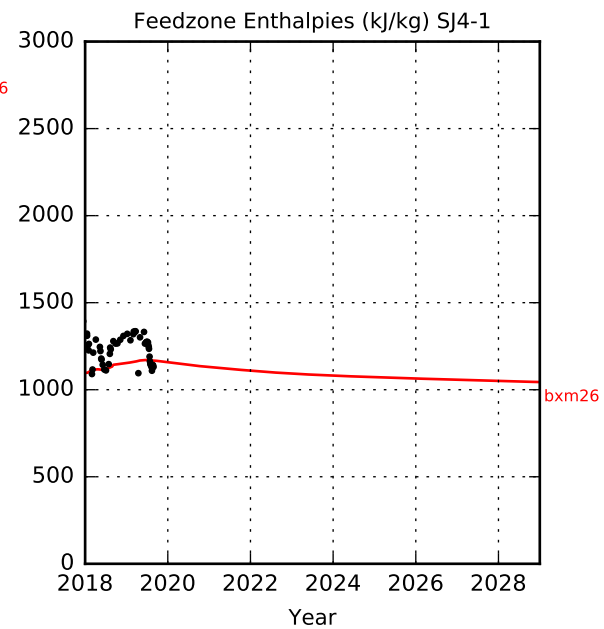
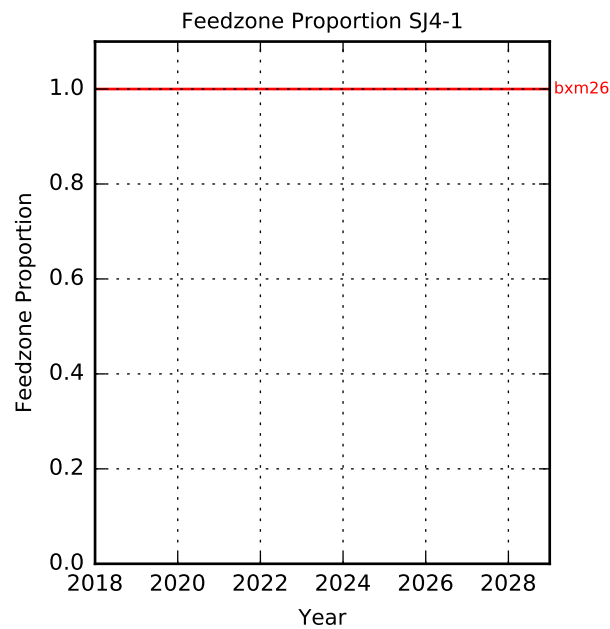
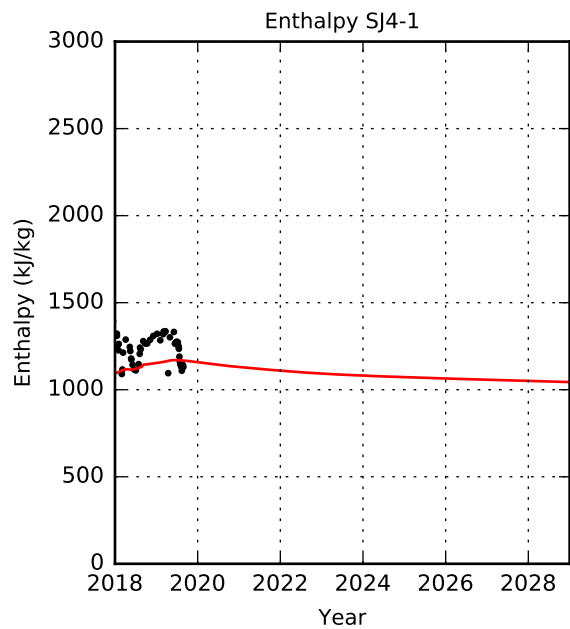
Feedzone Elevations

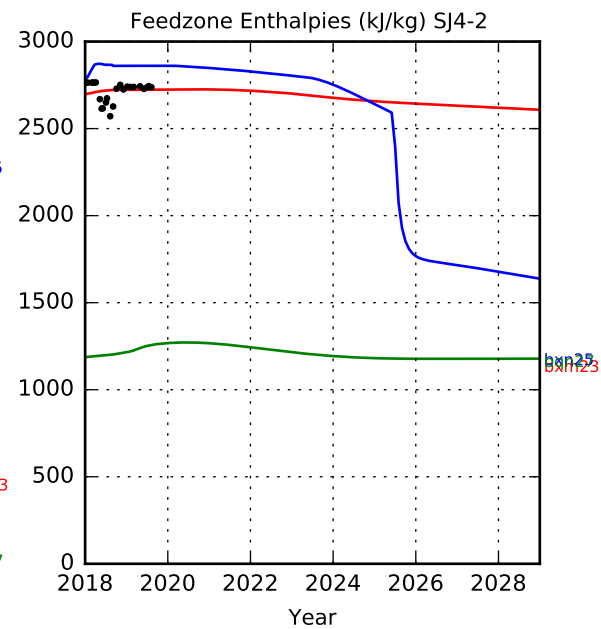
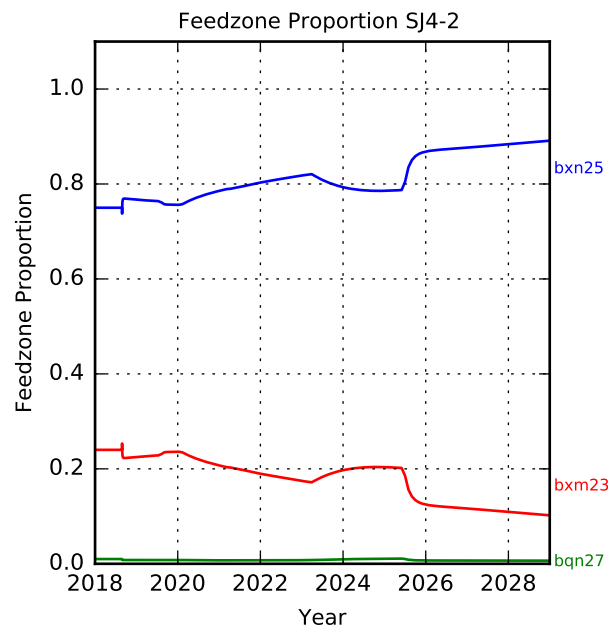
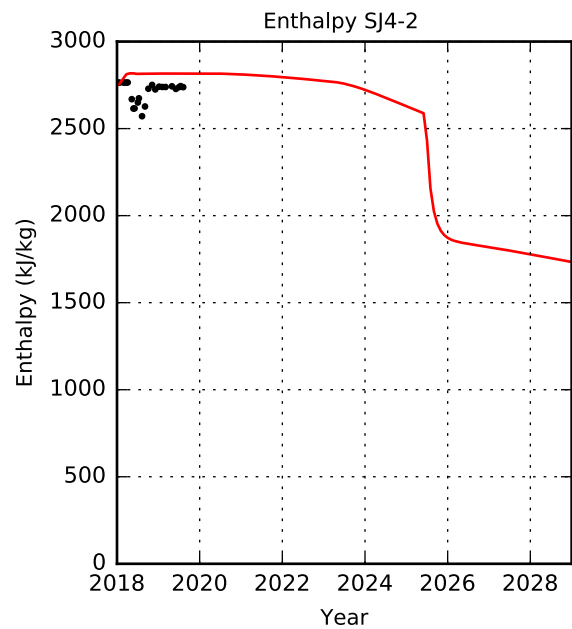
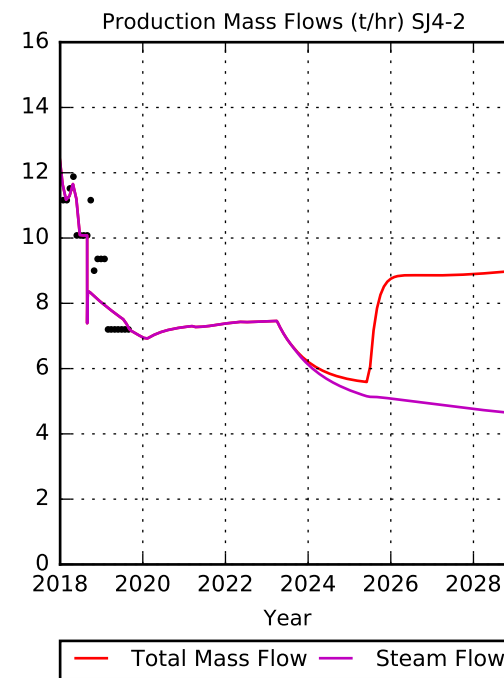
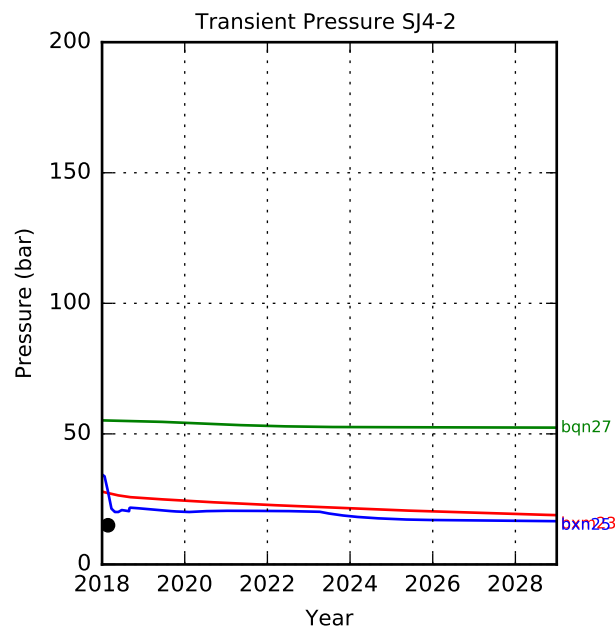
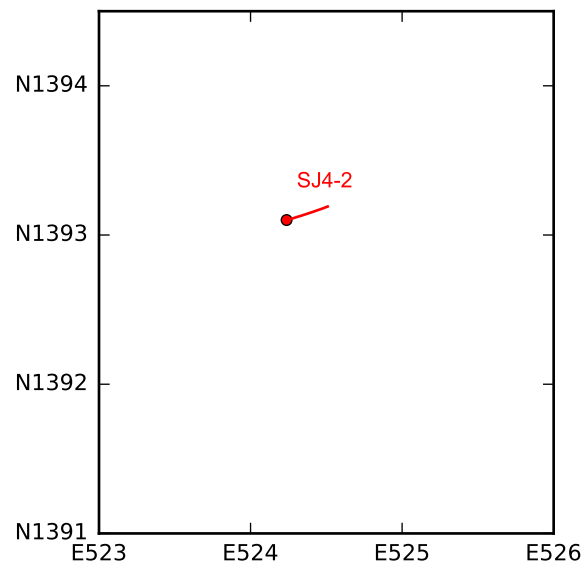
-1500.0 masl

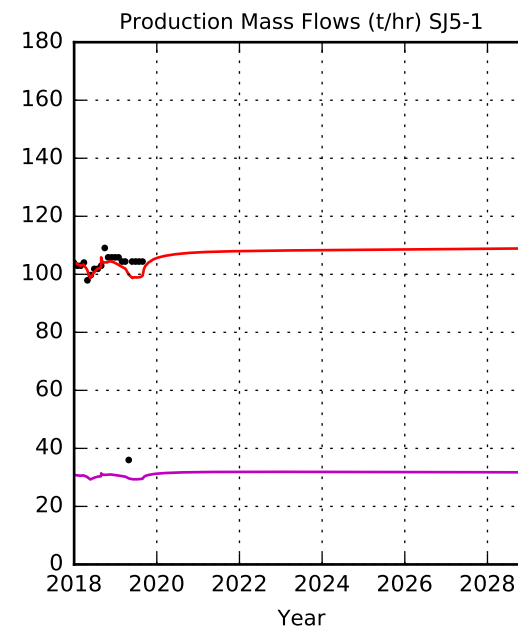
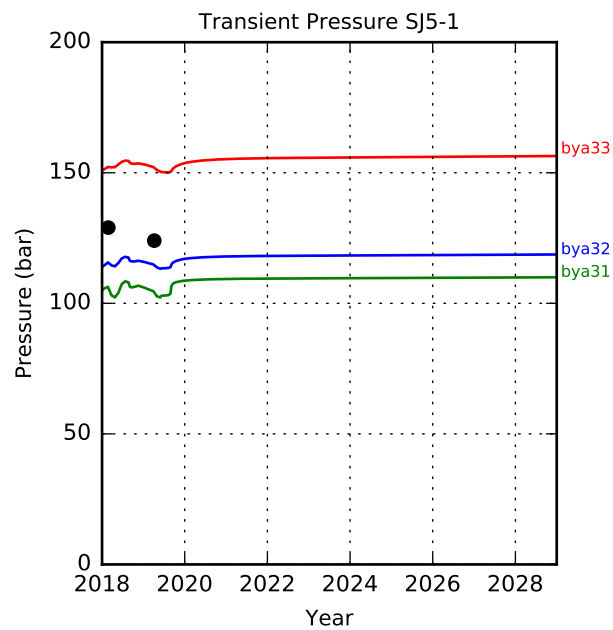
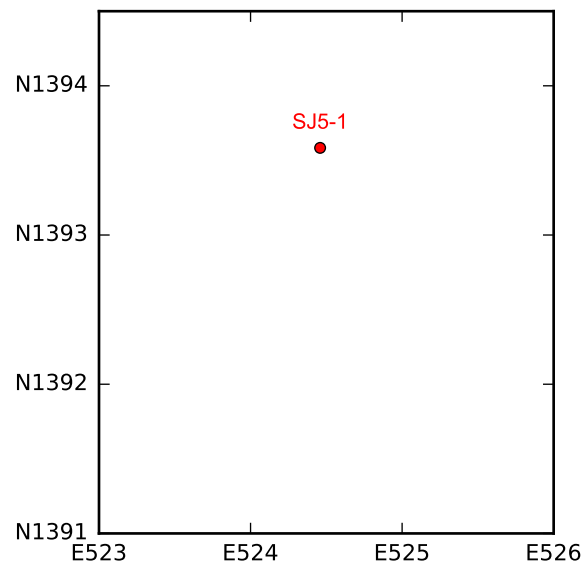




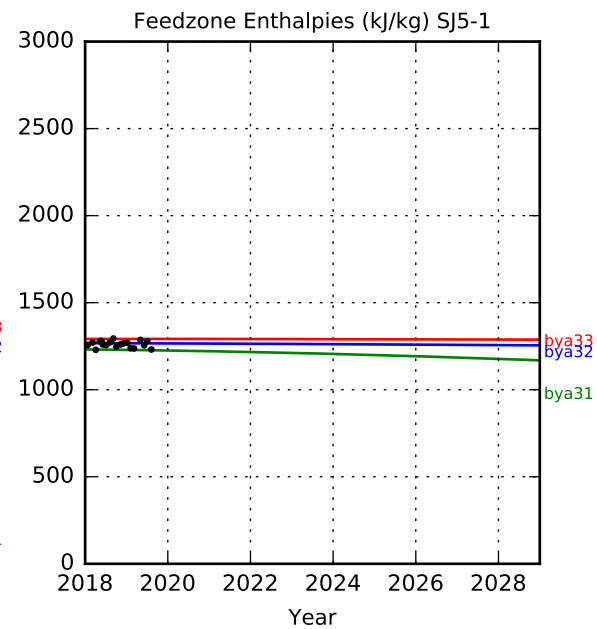
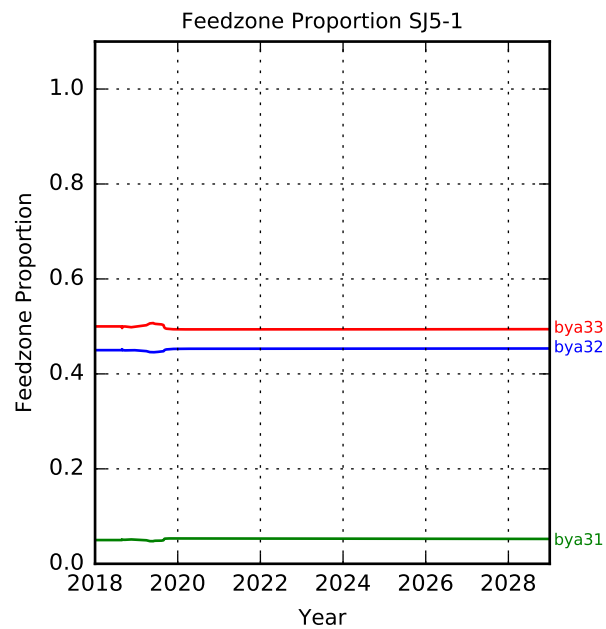
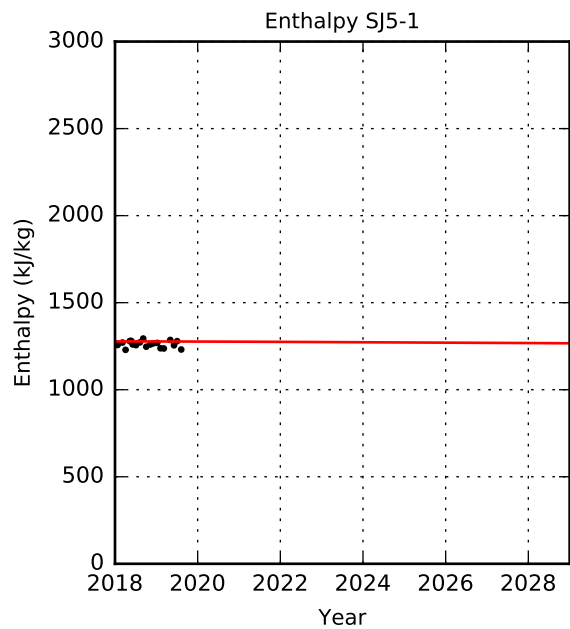
Feedzone Elevations
-525.0 masl

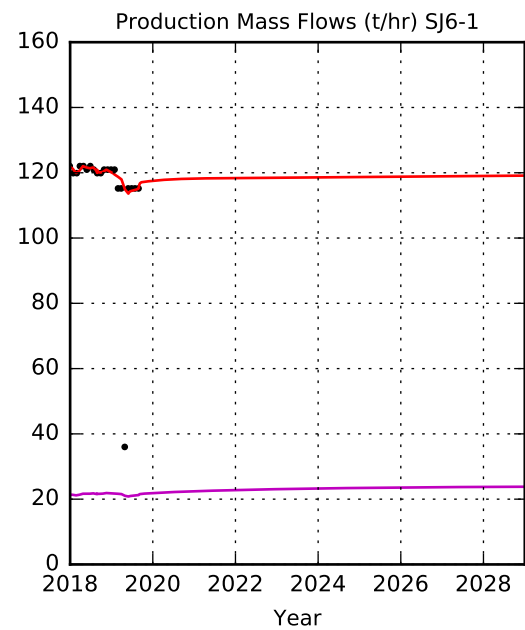
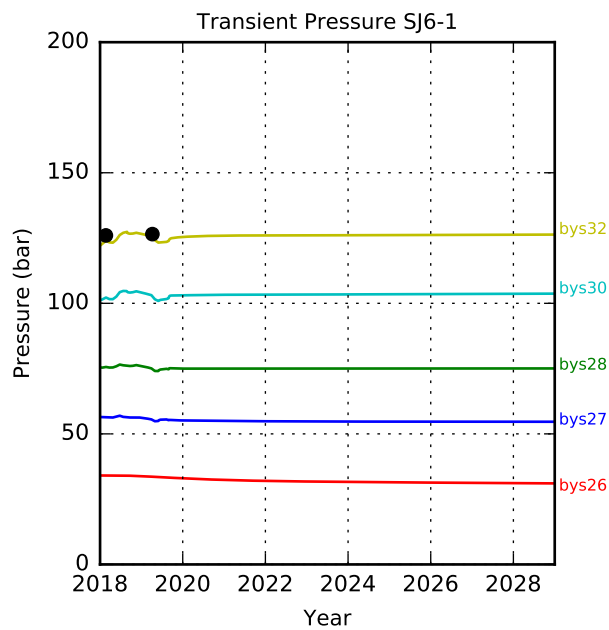
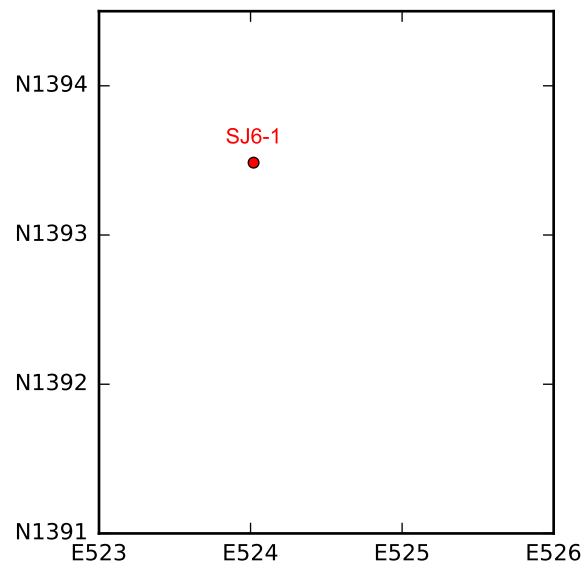






Feedzone Elevations
-2000.0 masl -1700.0 masl -1500.0 masl

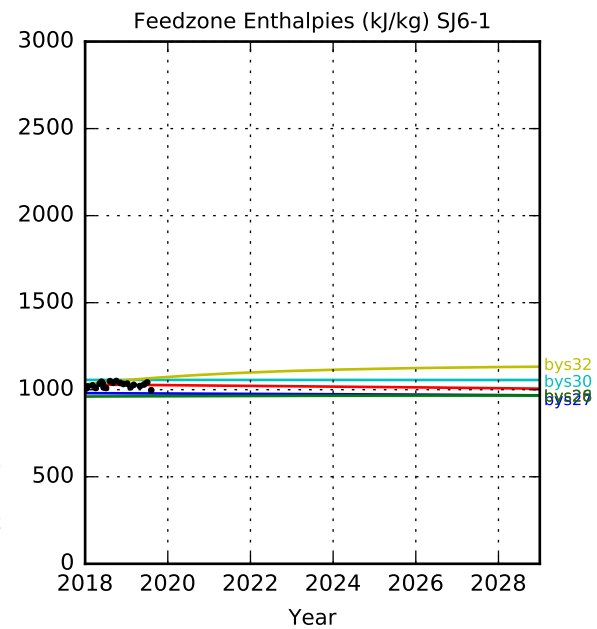
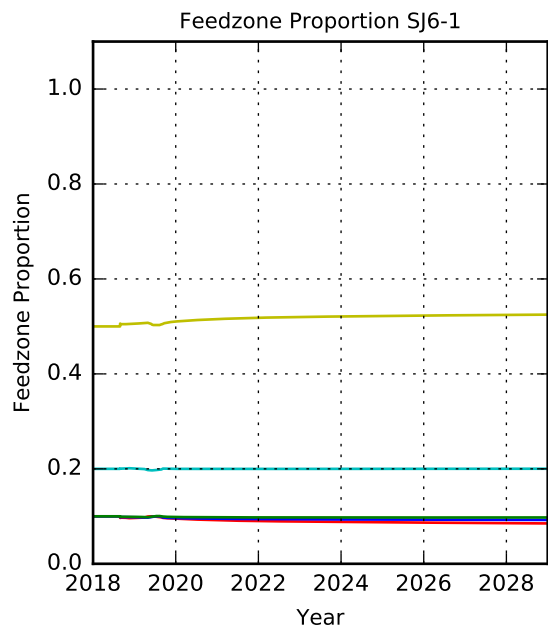
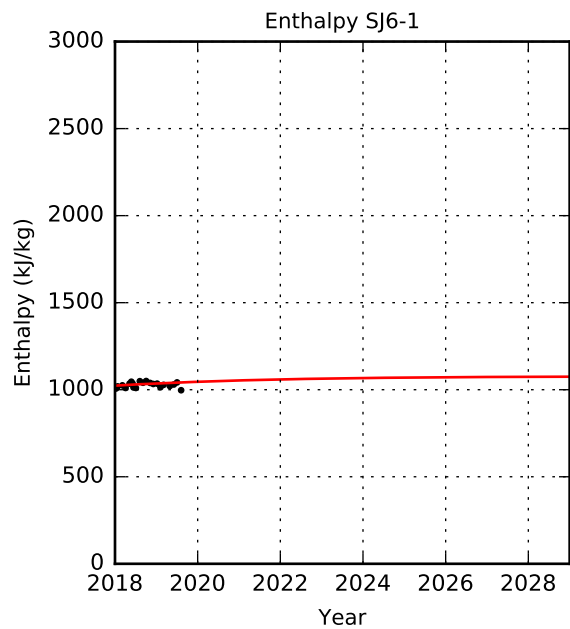


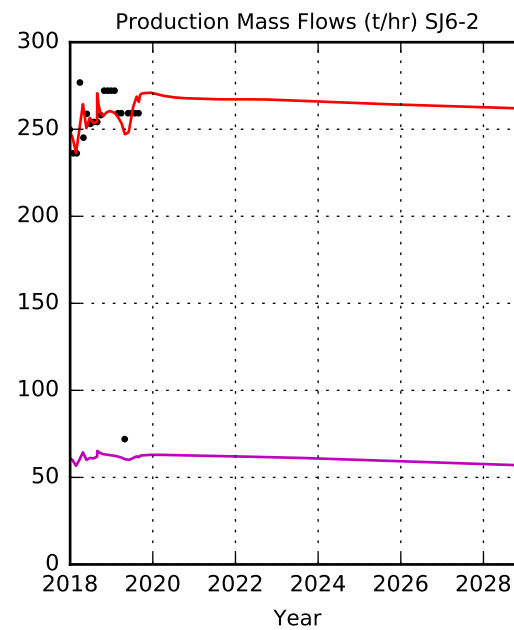
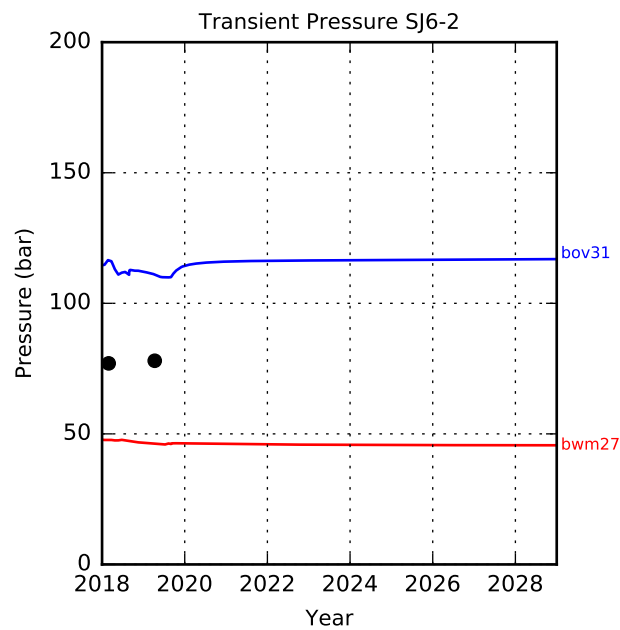
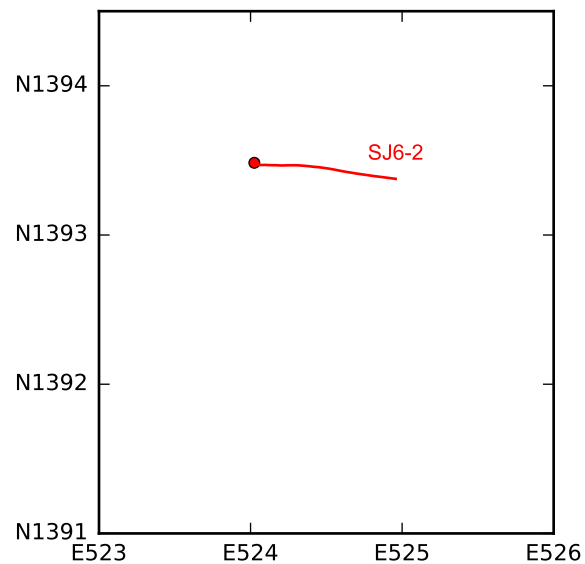


Feedzone Elevations

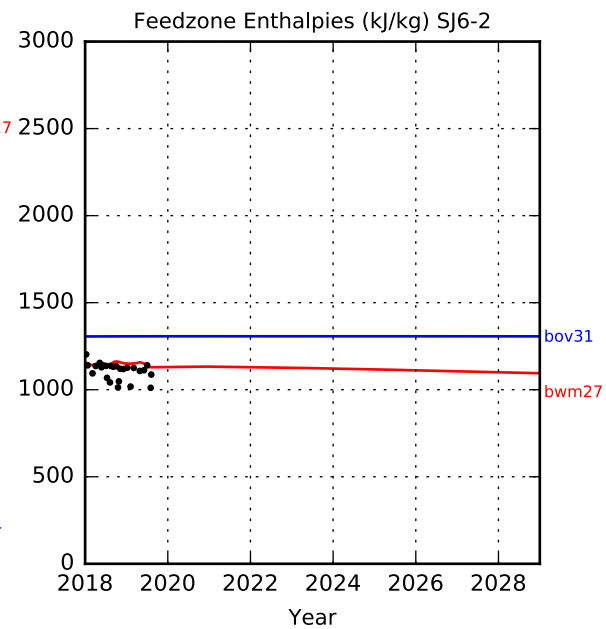
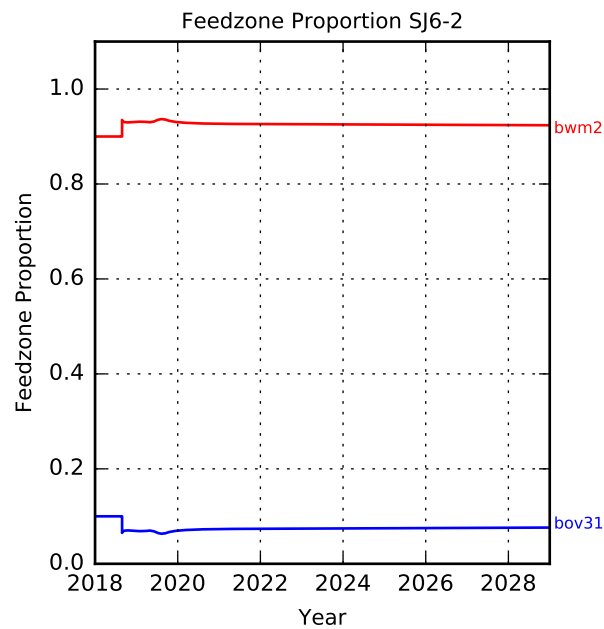
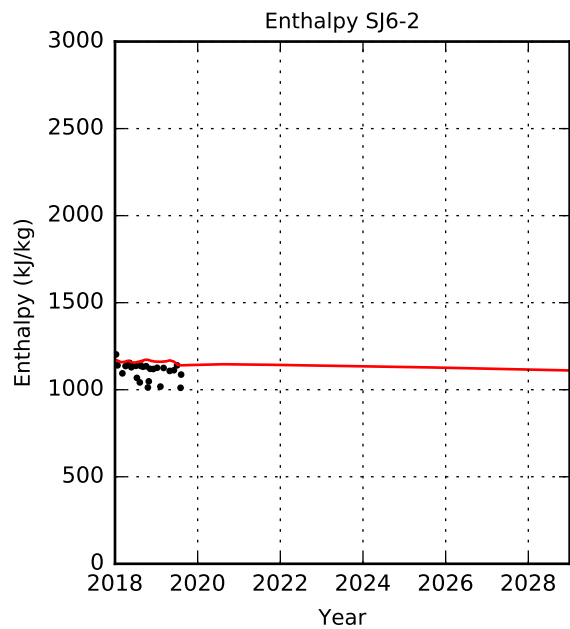
-525.0 masl	-700.0 masl	-900.0 masl
-1300.0 masl	-1700.0 masl	

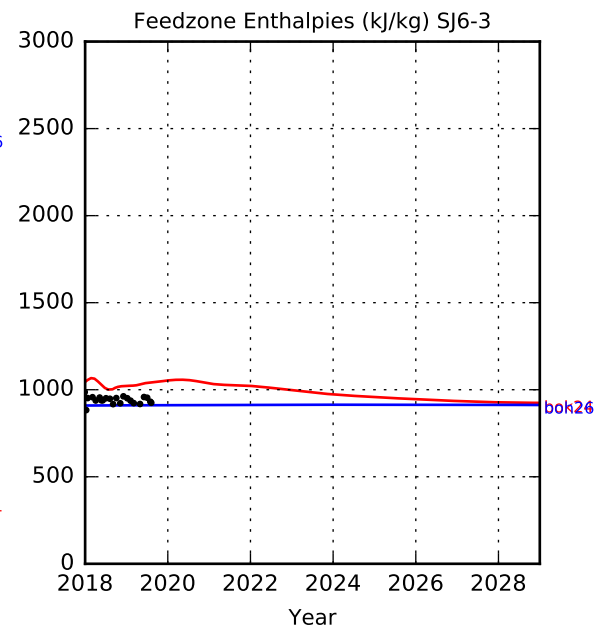
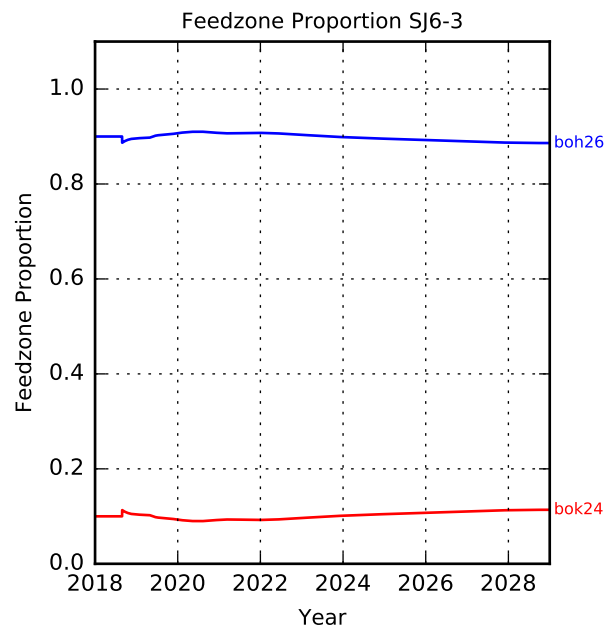
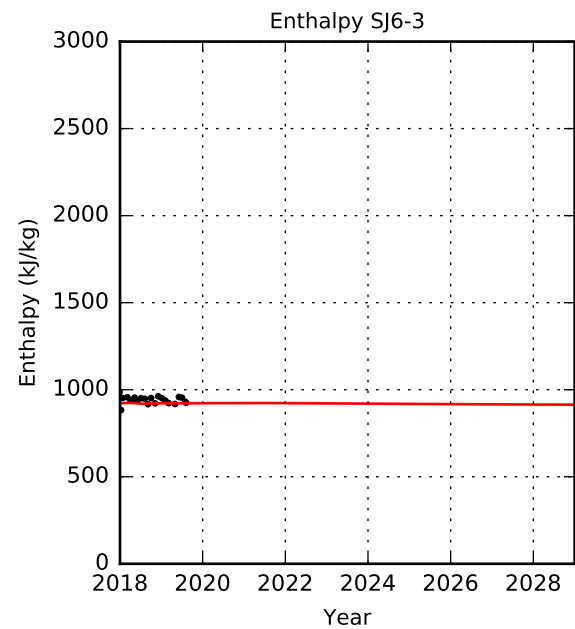
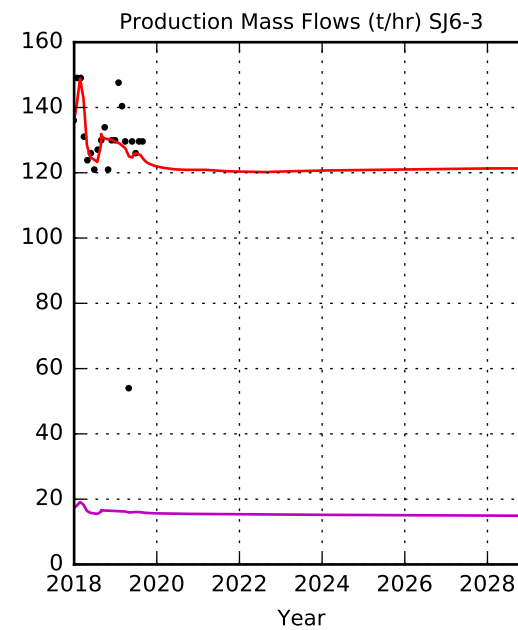
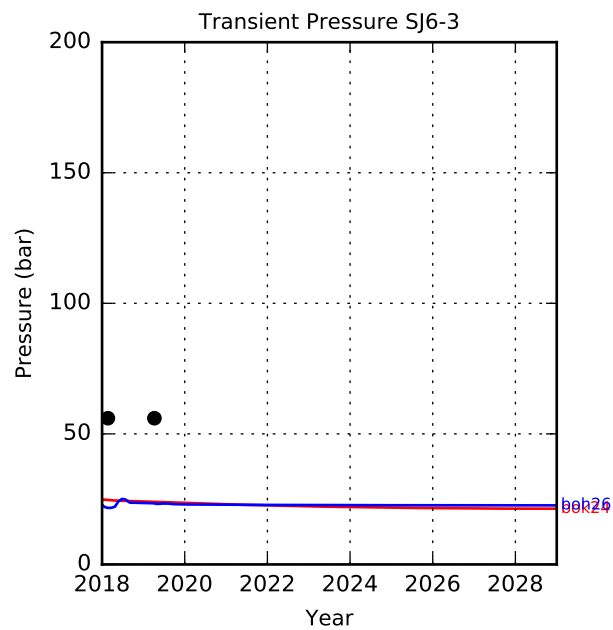
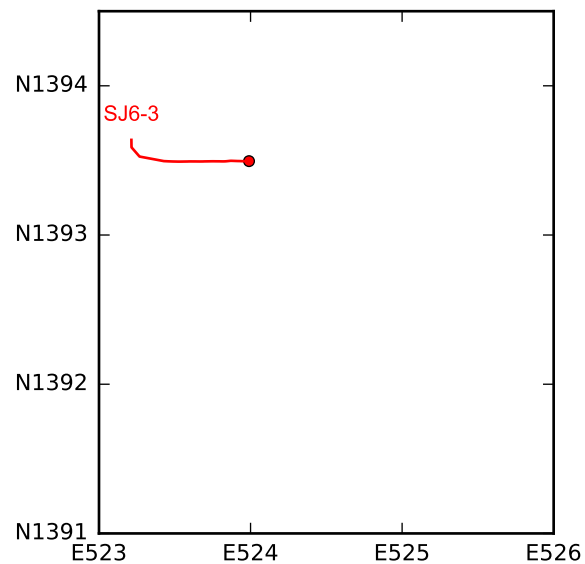
— Total Mass Flow — Steam Flow

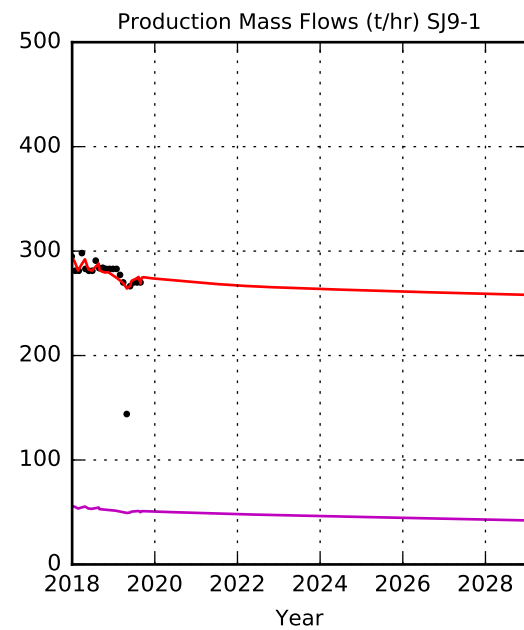
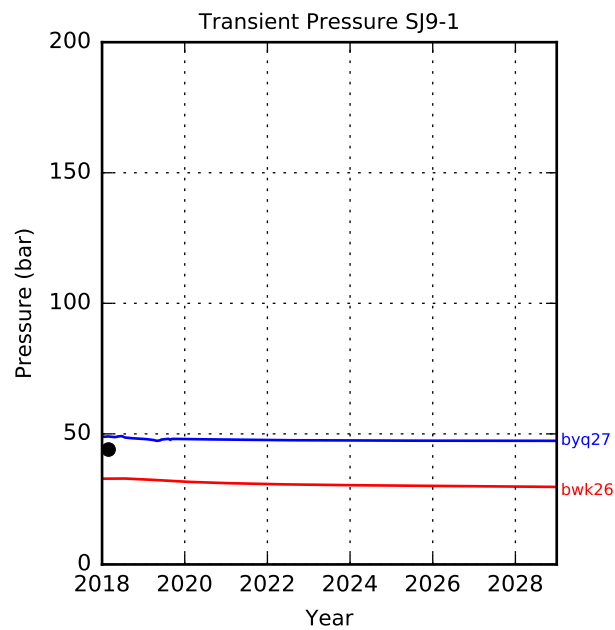
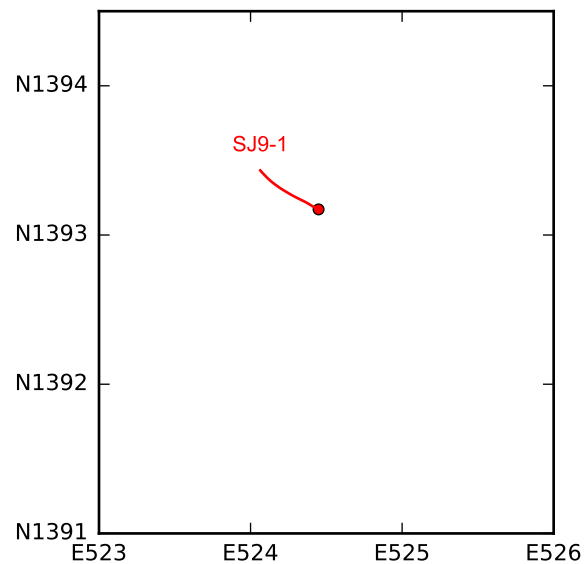




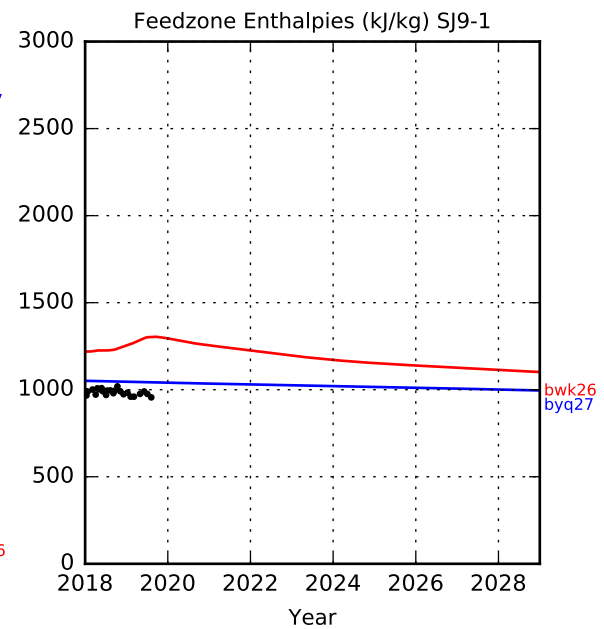
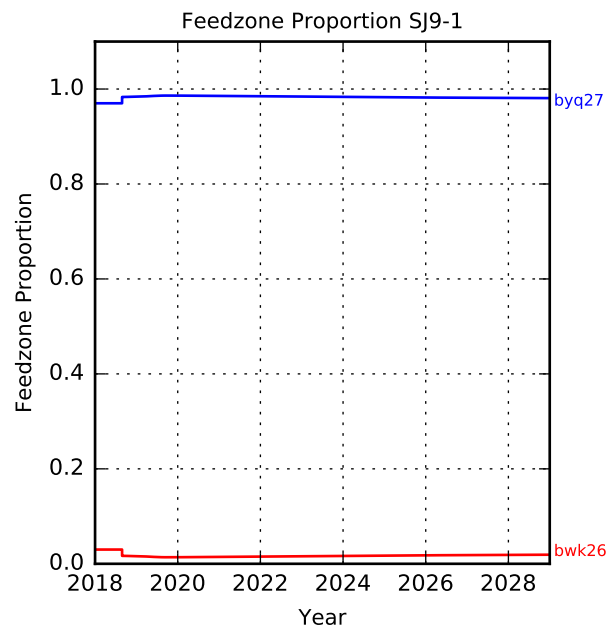
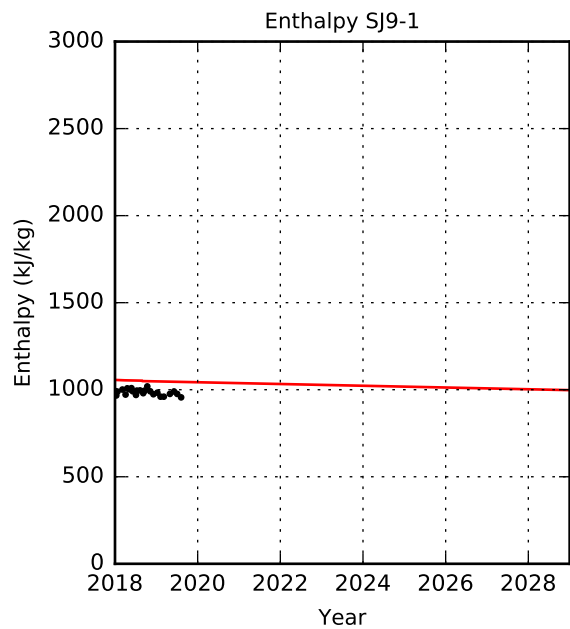
Feedzone Elevations
-700.0 masl -1500.0 masl

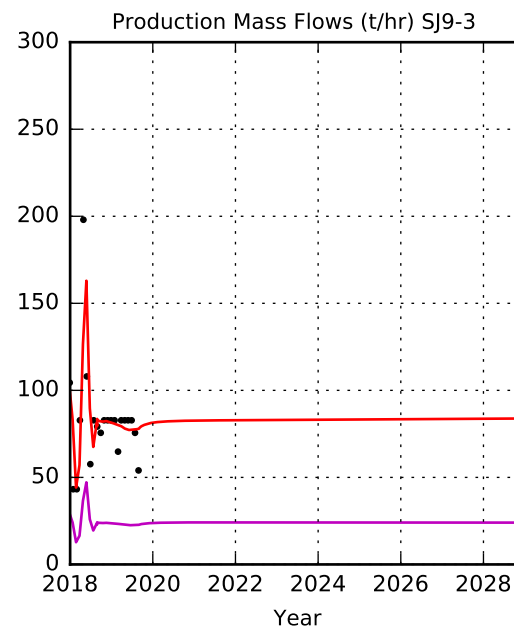
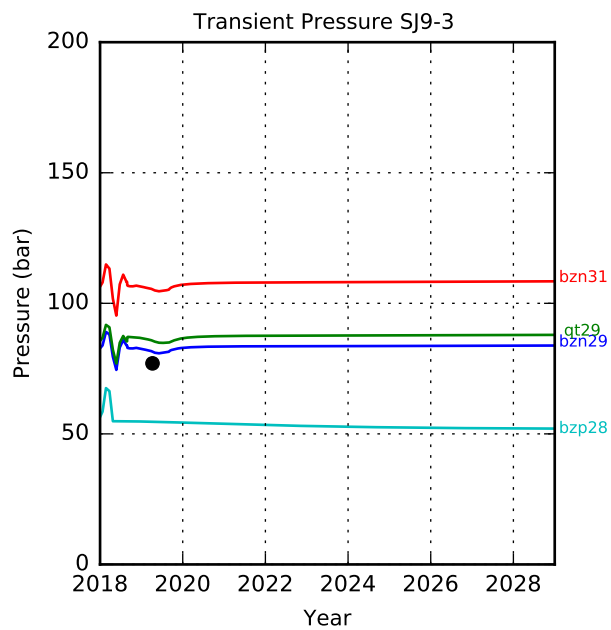
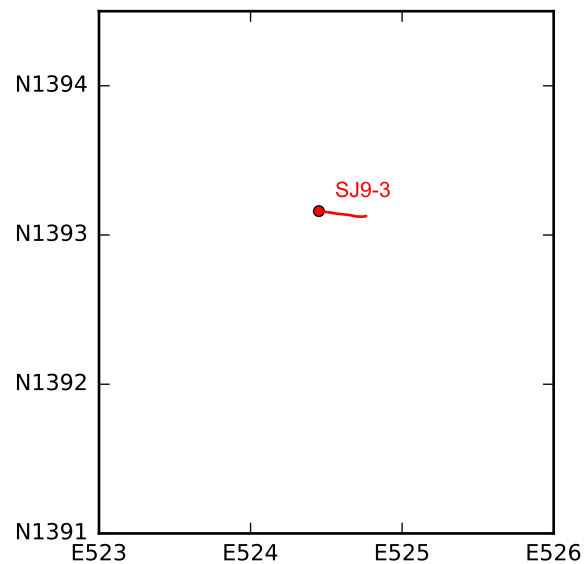






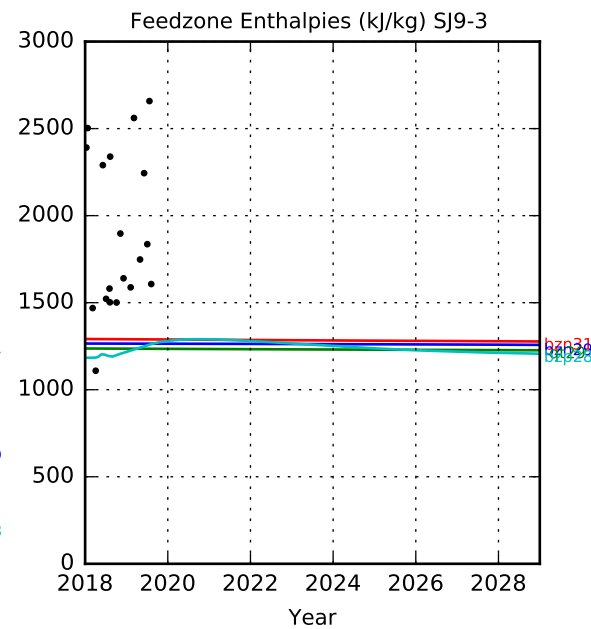
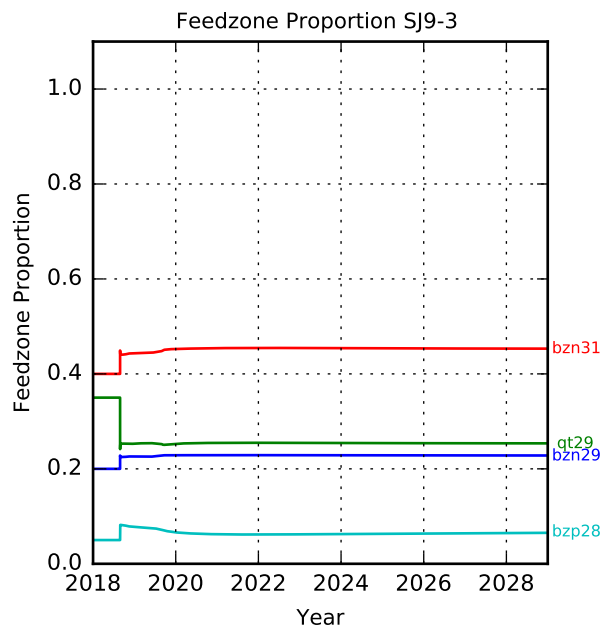
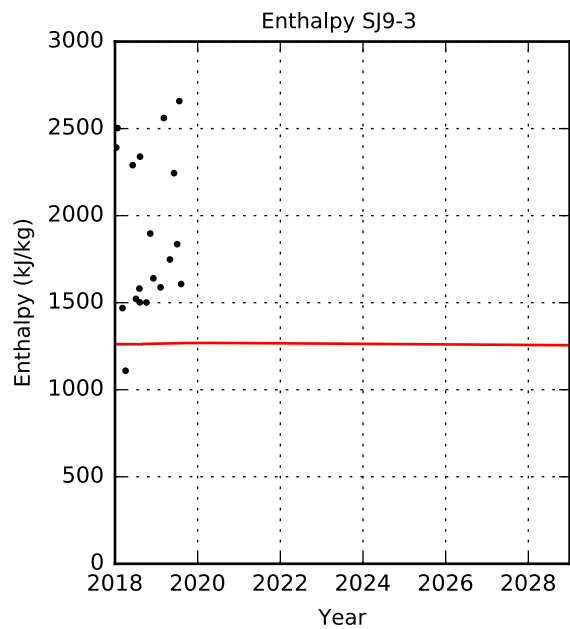
Feedzone Elevations
-525.0 masl -700.0 masl

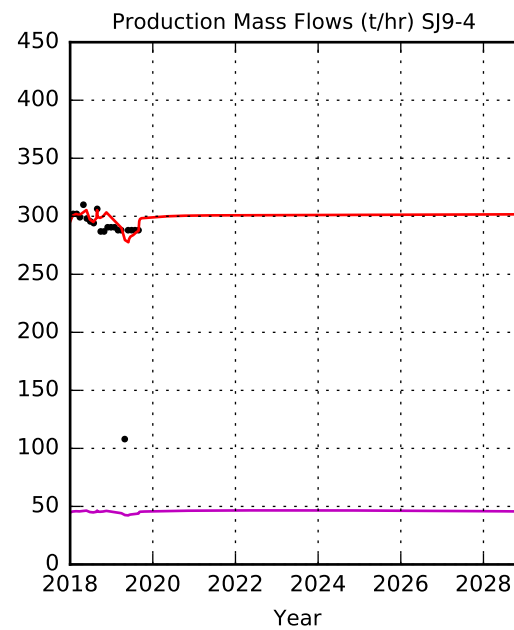
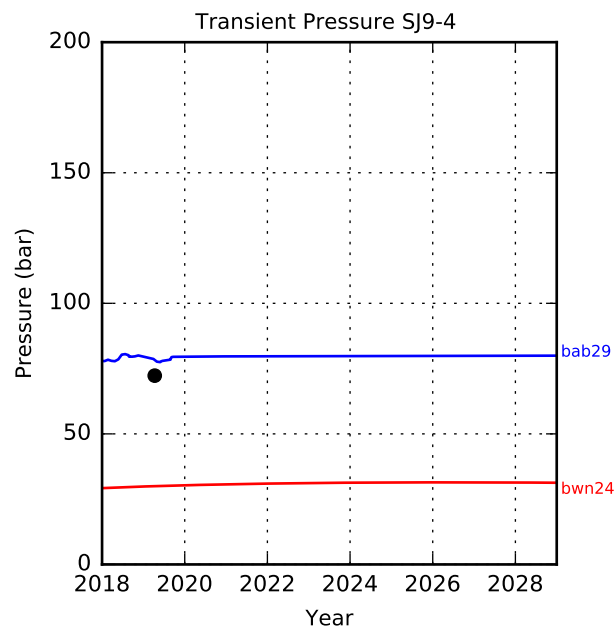
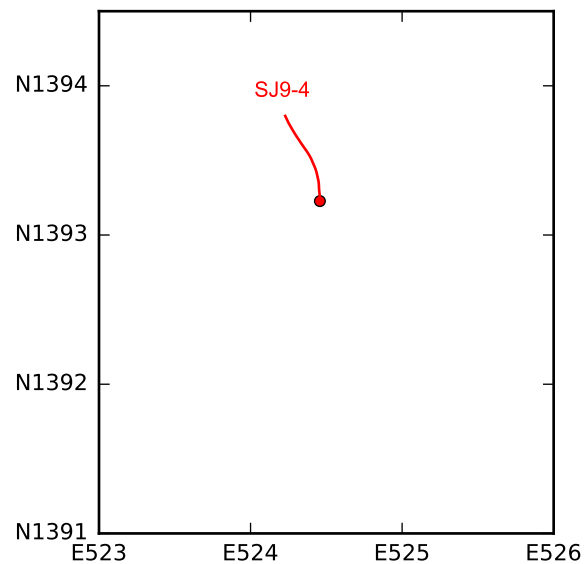




Feedzone Elevations

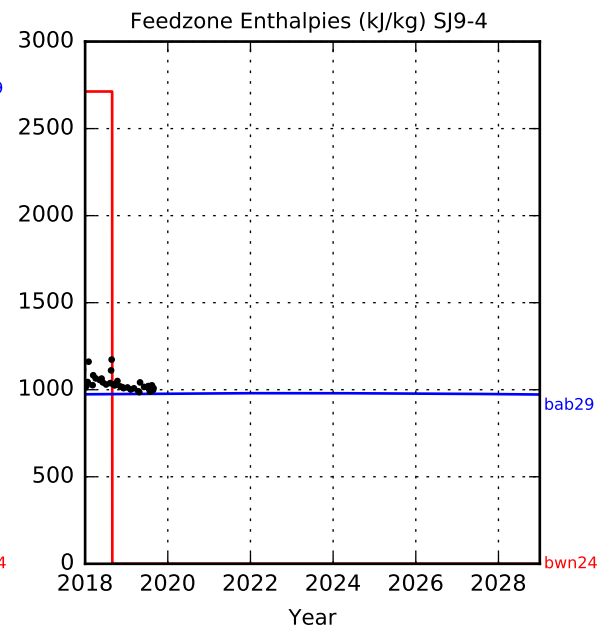
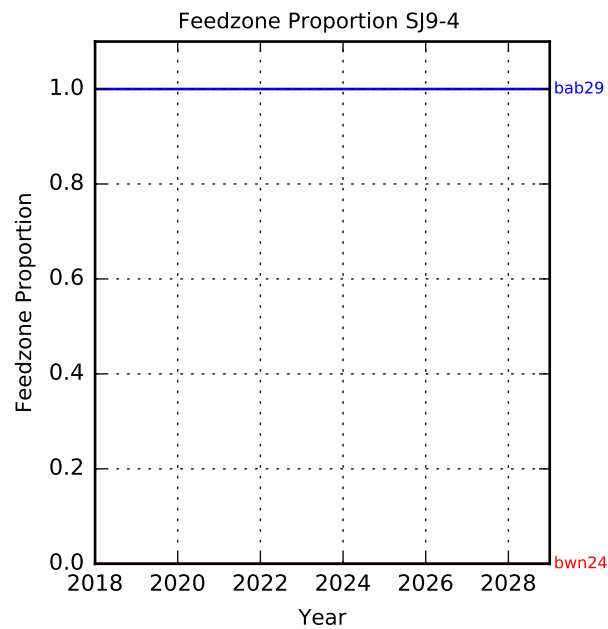
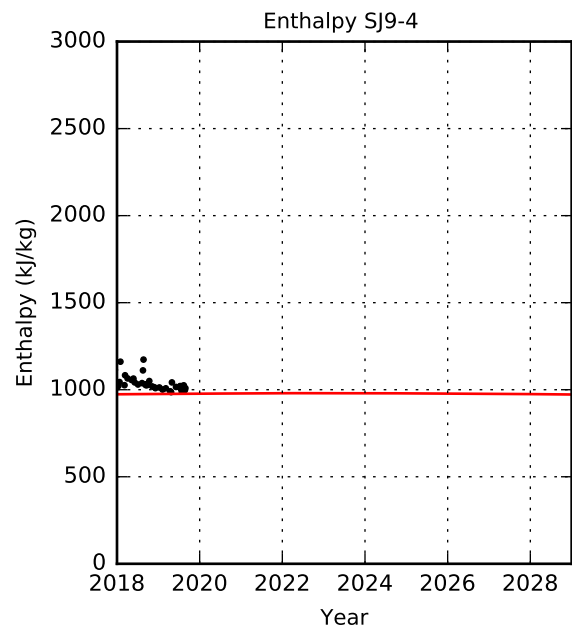
- 1500.0 masl
- 1100.0 masl
- 1100.0 masl
- 900.0 masl

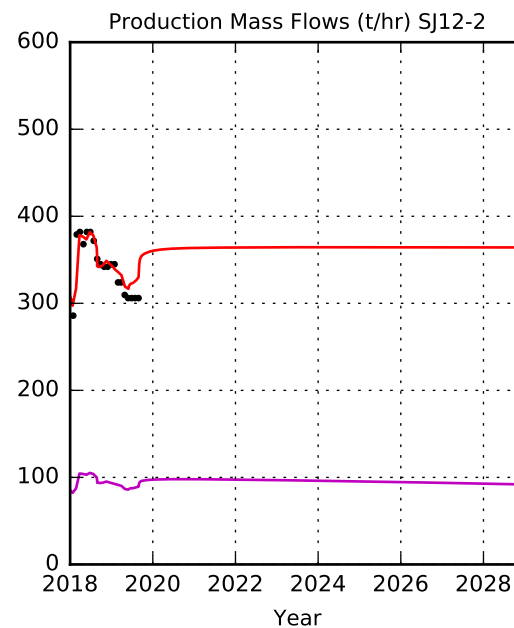
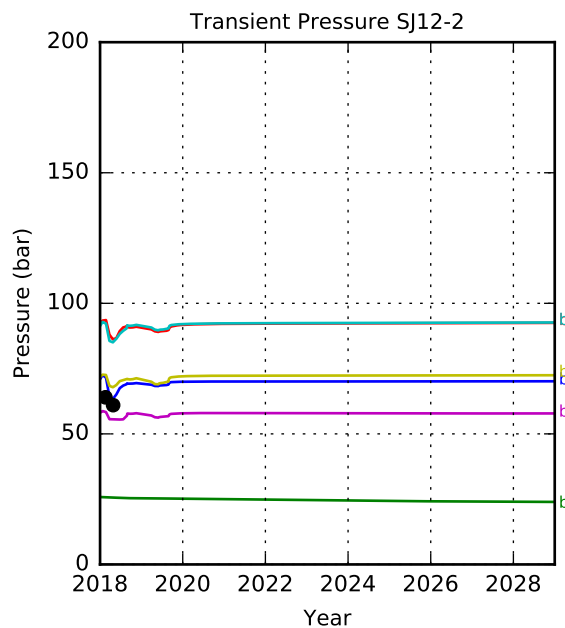
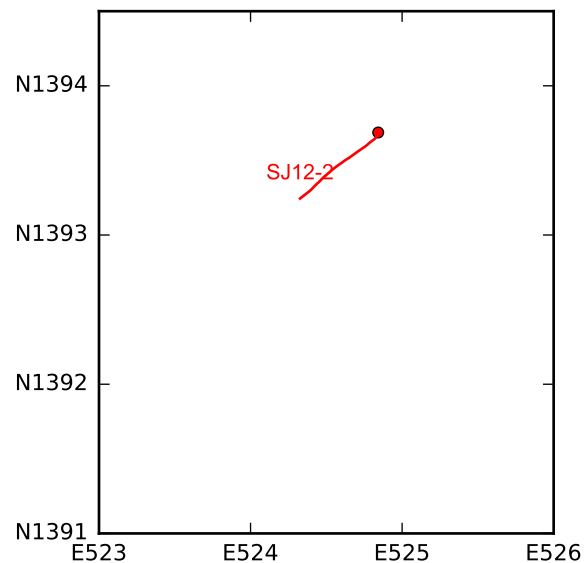




Feedzone Elevations
-250.0 masl -1100.0 masl

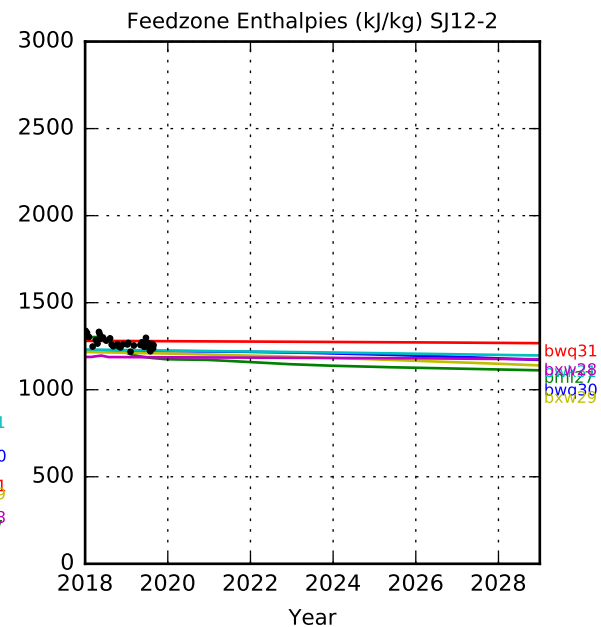
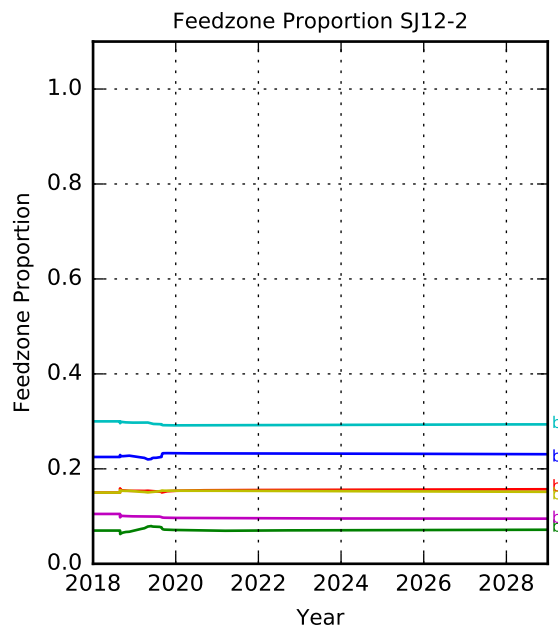
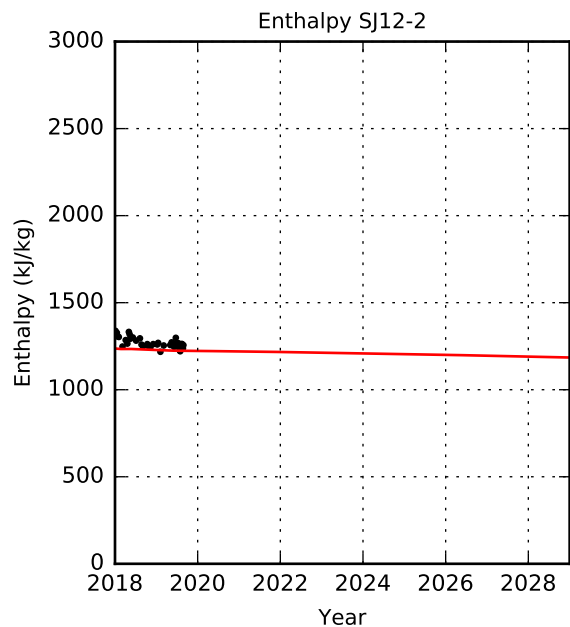
— Total Mass Flow — Steam Flow

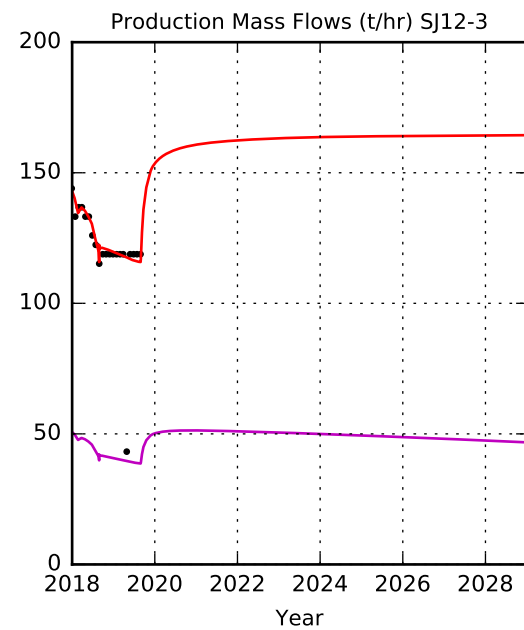
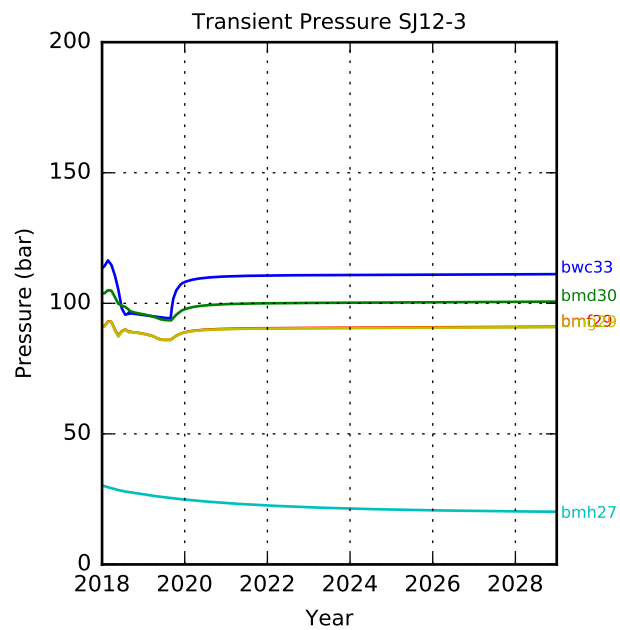
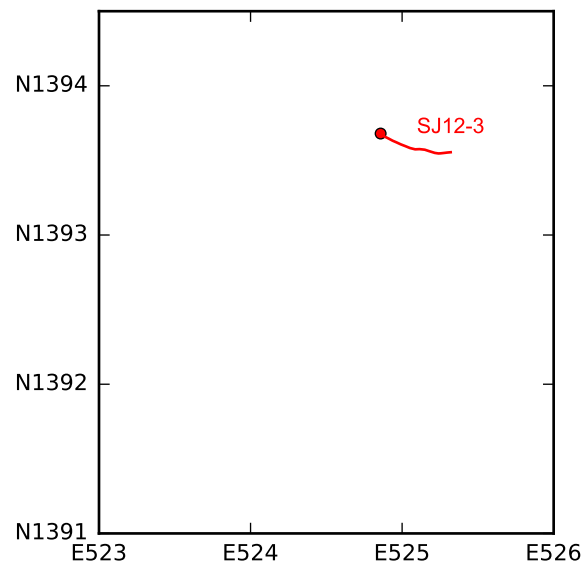




Feedzone Elevations

Feedzone	Elevation (masl)
bxw29	-1500.0
bxw30	-1300.0
bxw28	-700.0
bmi27	-1500.0
bxw29	-1100.0
bxw28	-900.0

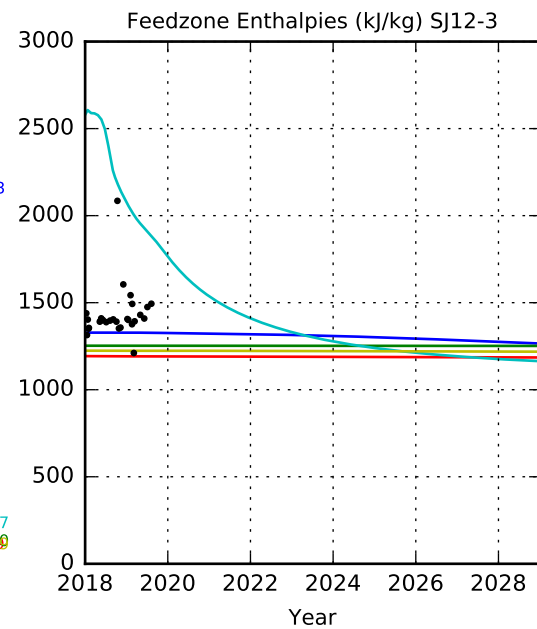
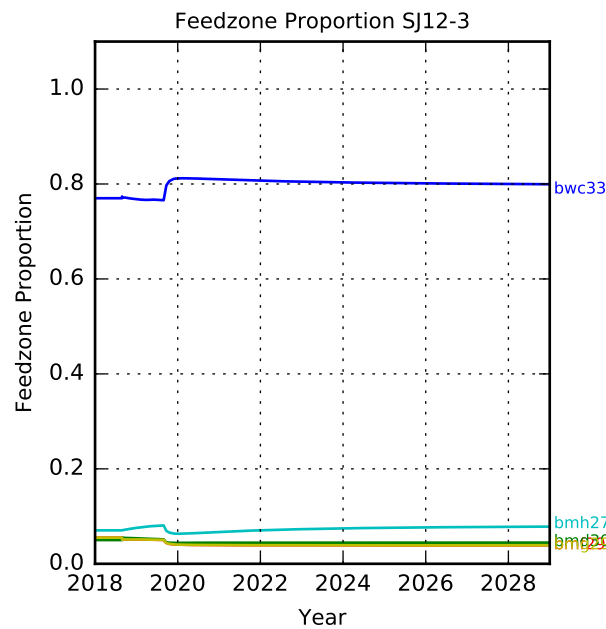
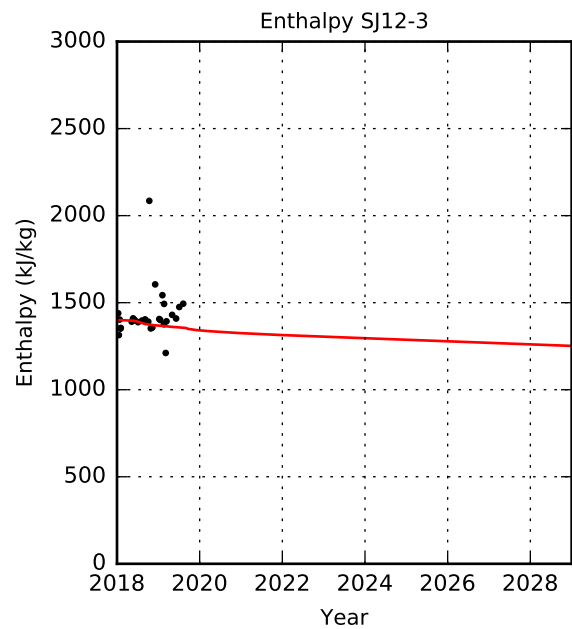


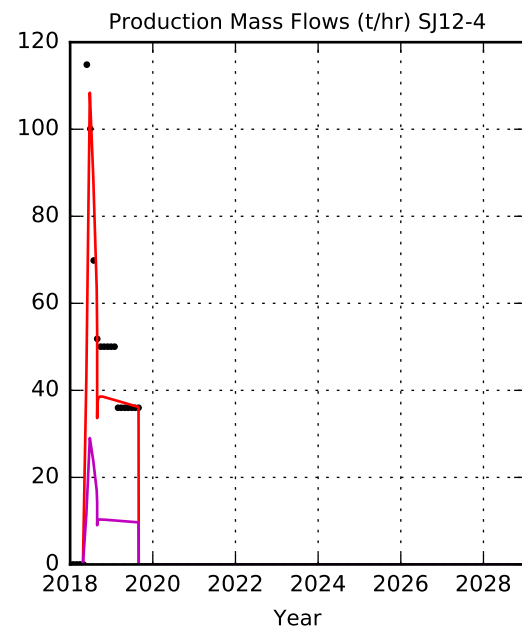
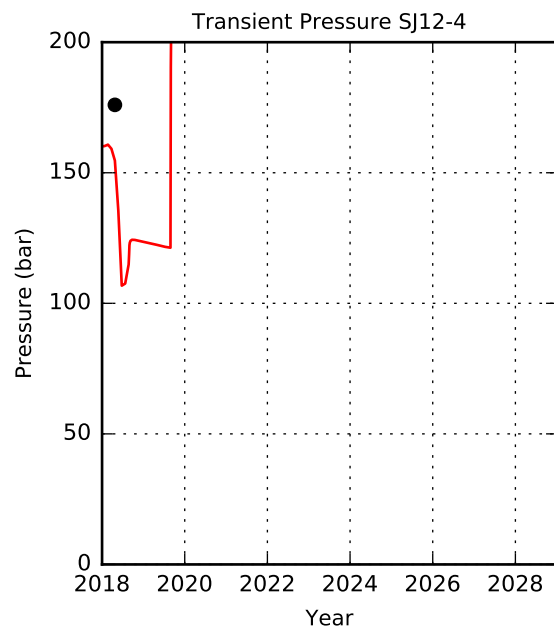
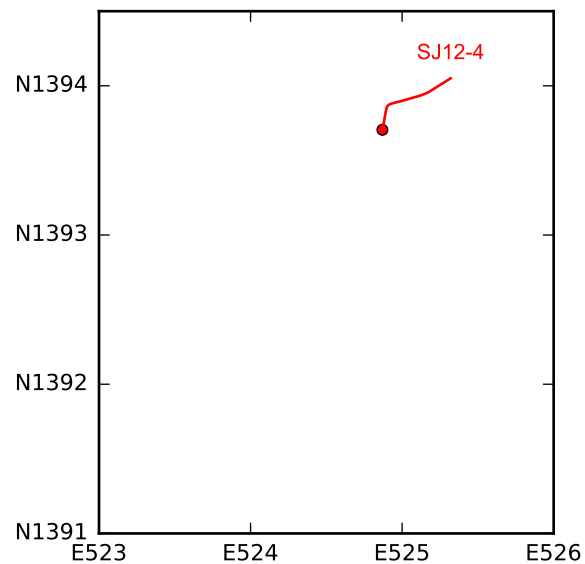


Feedzone Elevations

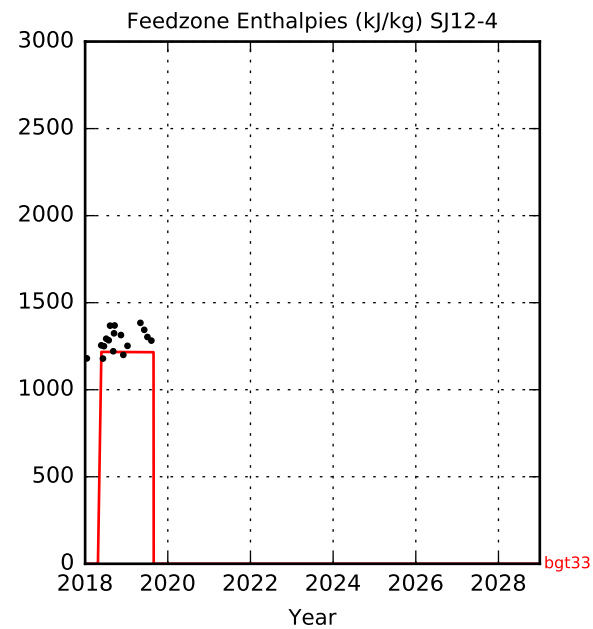
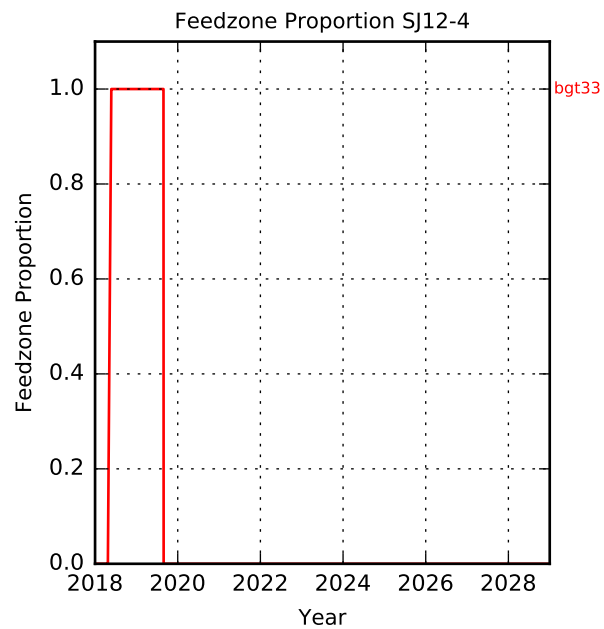
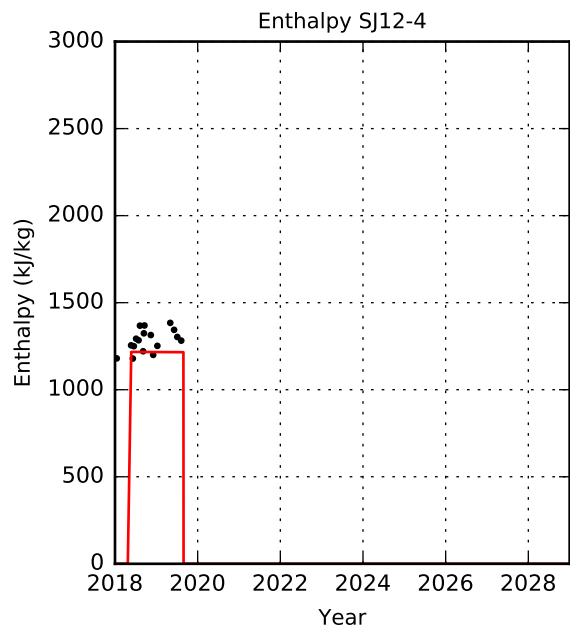
Feedzone	Elevation (masl)
-1100.0 masl	-1100.0 masl
-2000.0 masl	-2000.0 masl
-1300.0 masl	-1300.0 masl
-700.0 masl	-700.0 masl
-1100.0 masl	-1100.0 masl

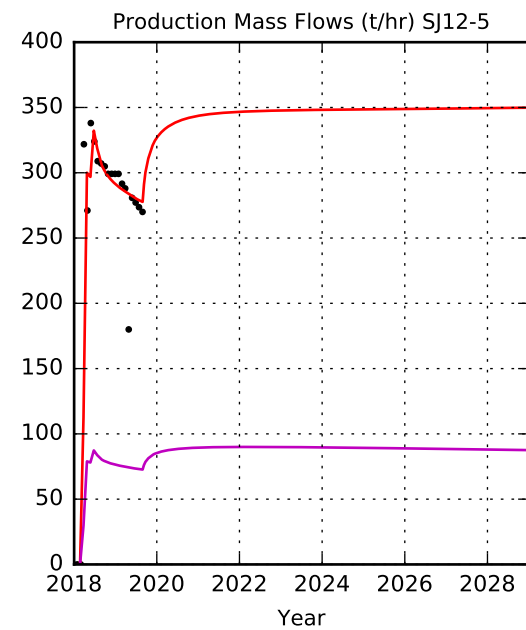
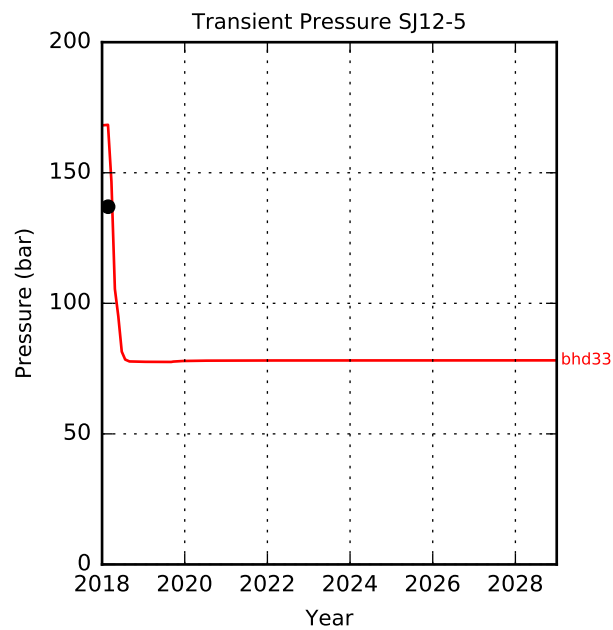
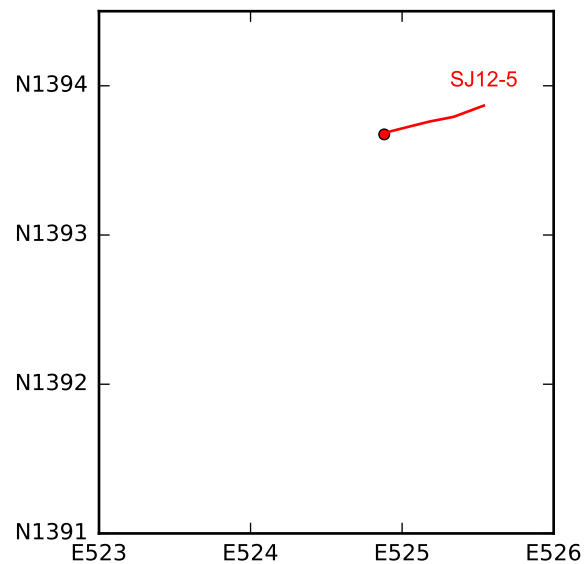
— Total Mass Flow — Steam Flow



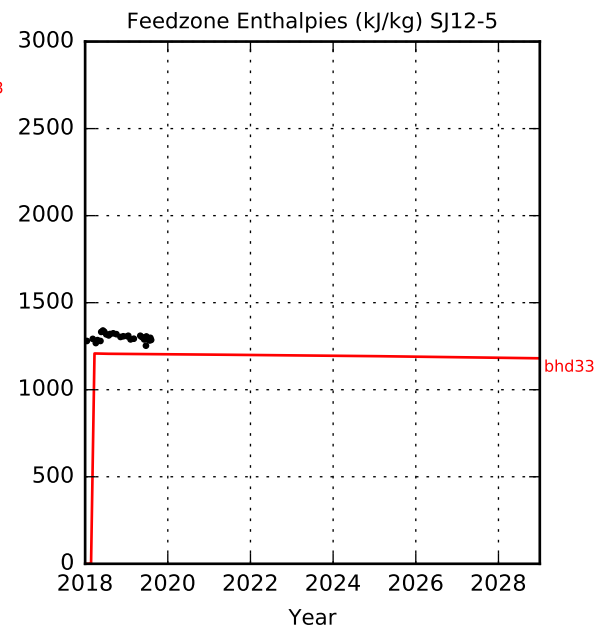
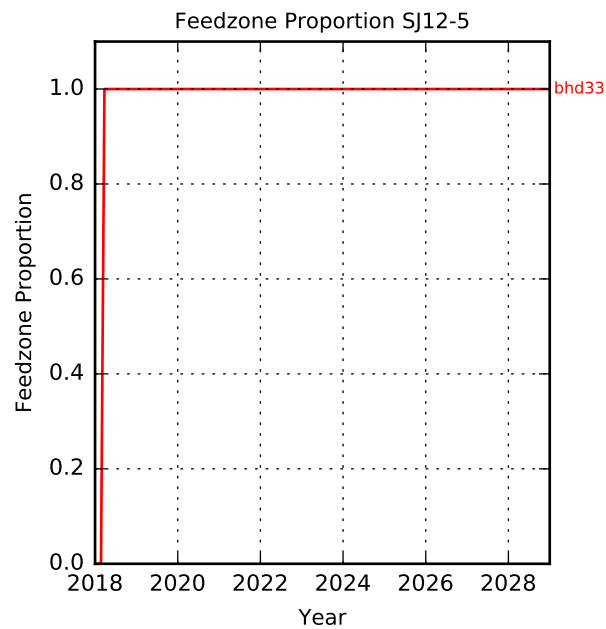
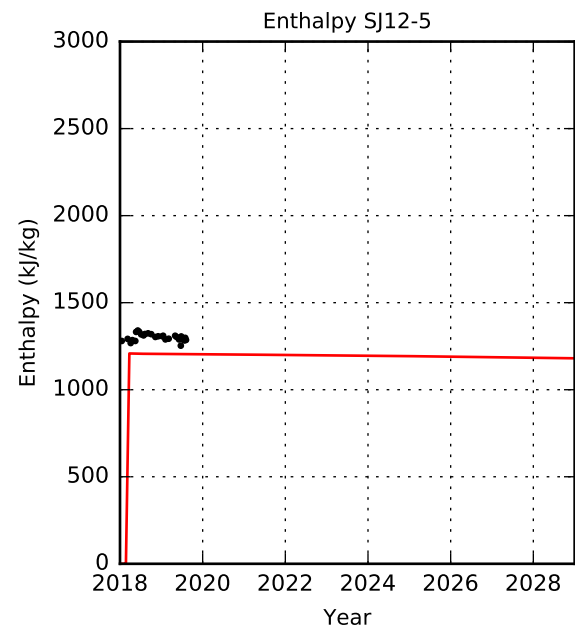


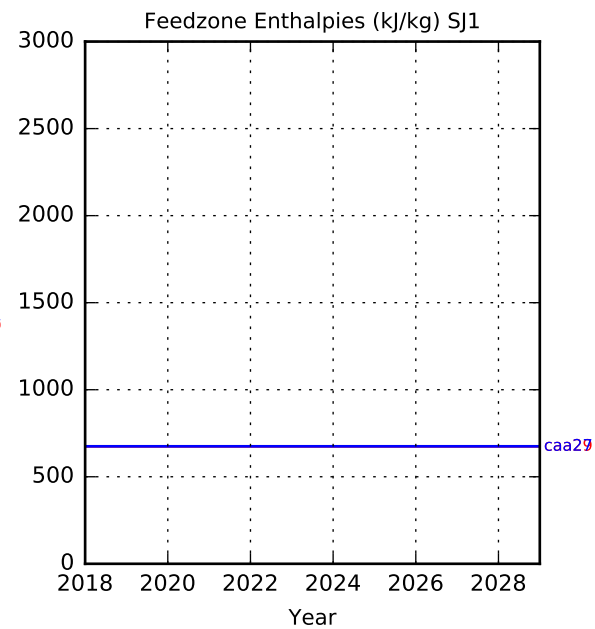
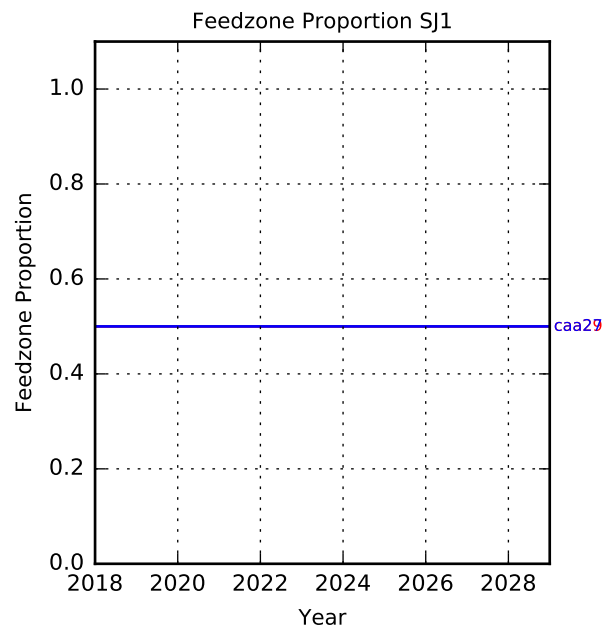
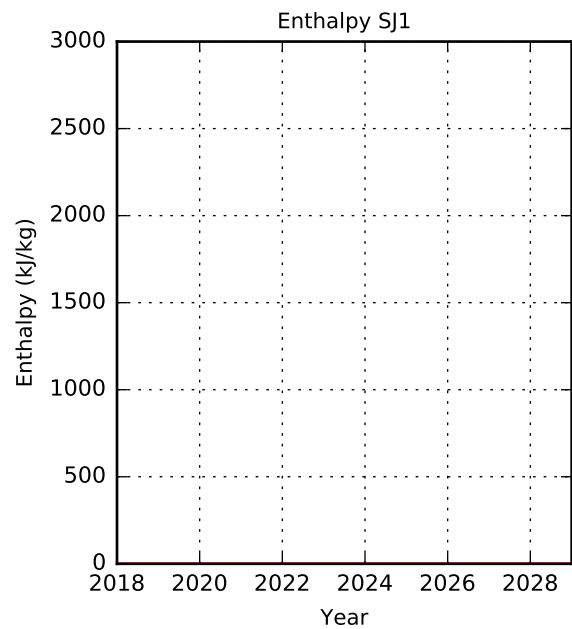
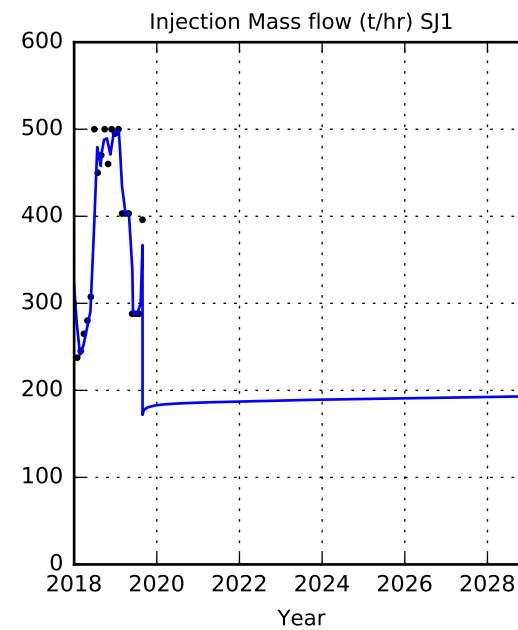
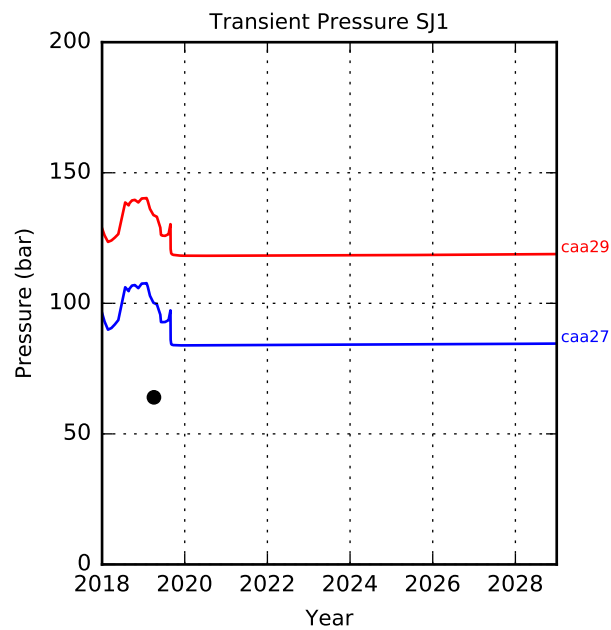
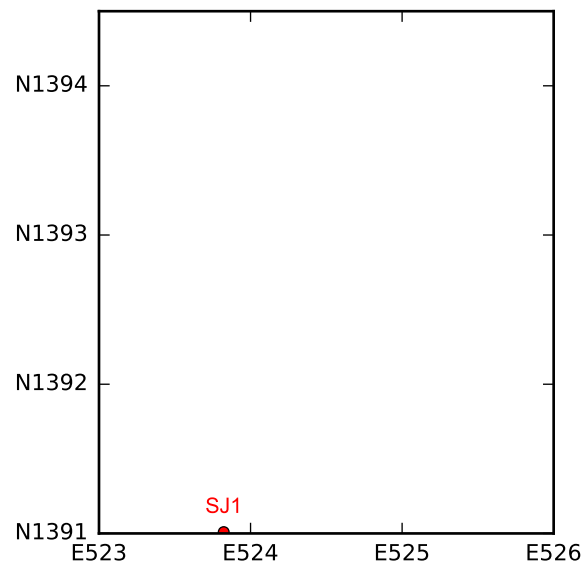
— Total Mass Flow — Steam Flow

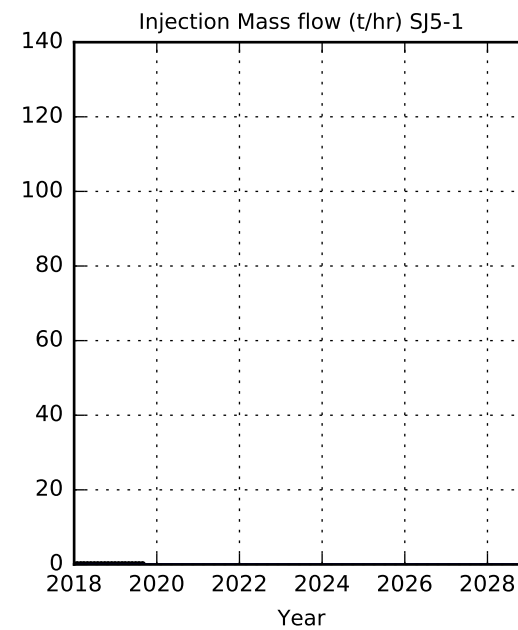
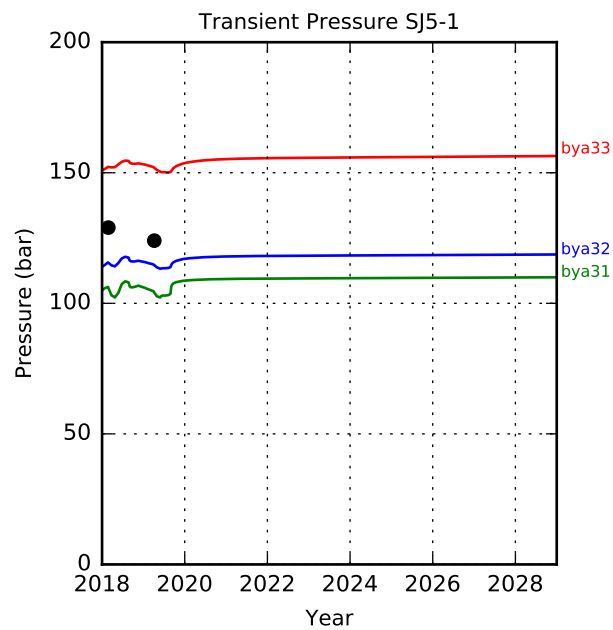
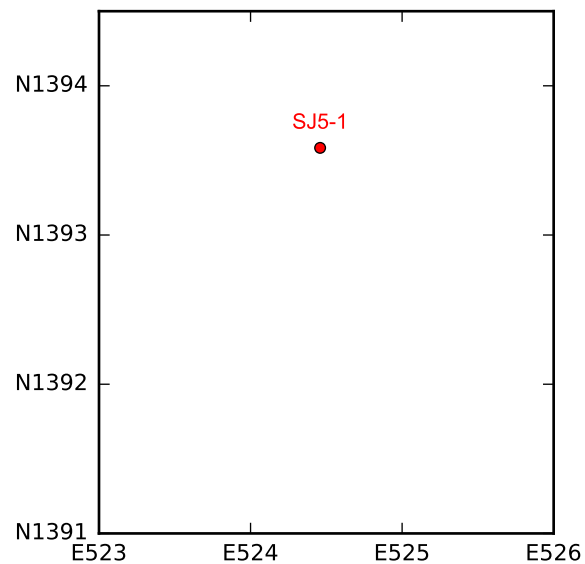




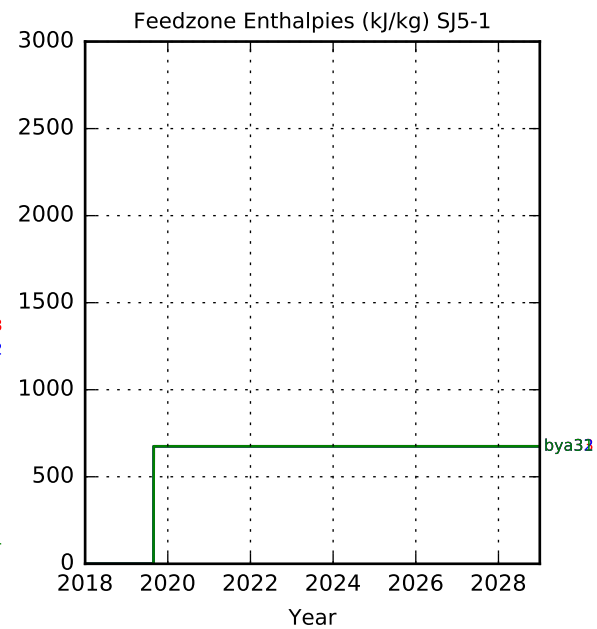
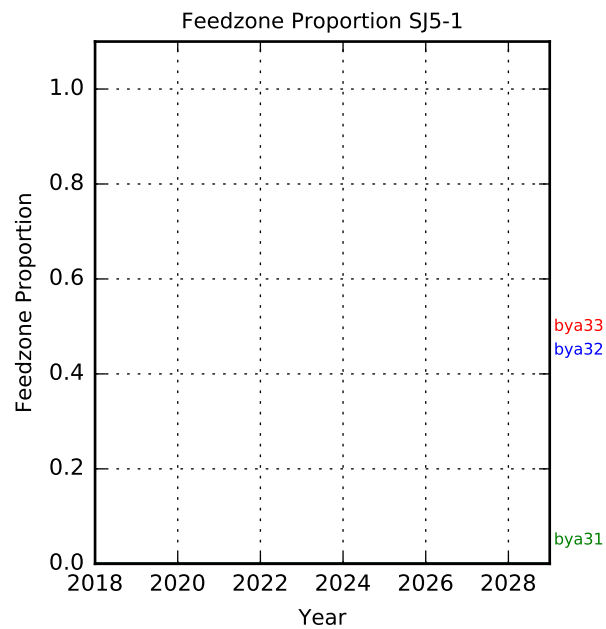
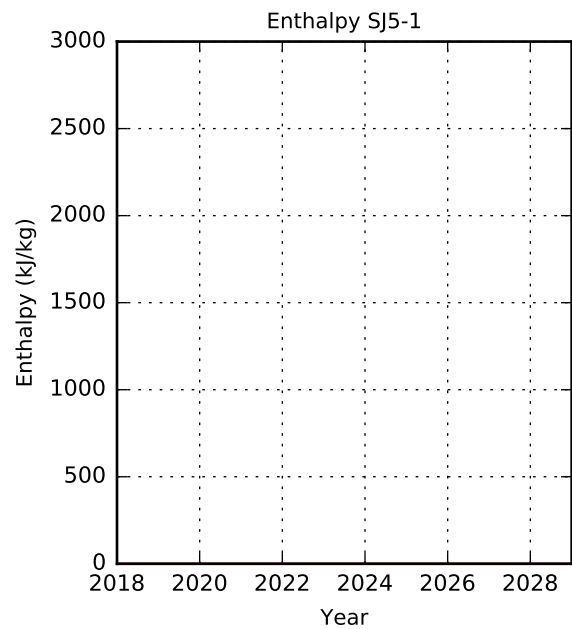
Feedzone Elevations
-2000.0 masl

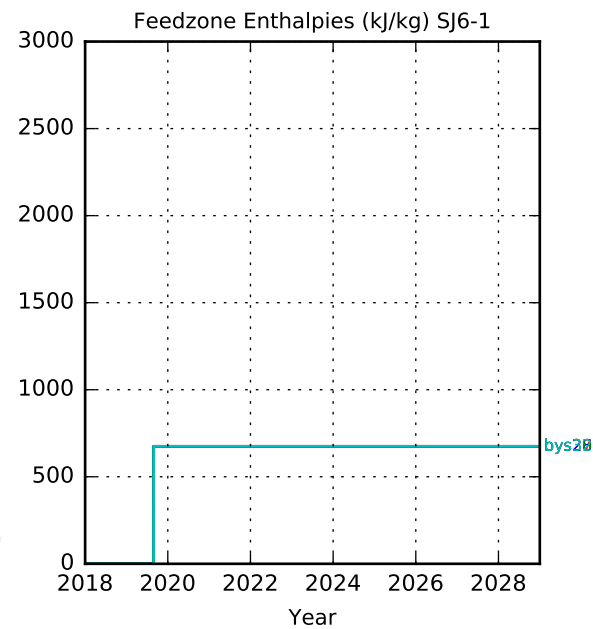
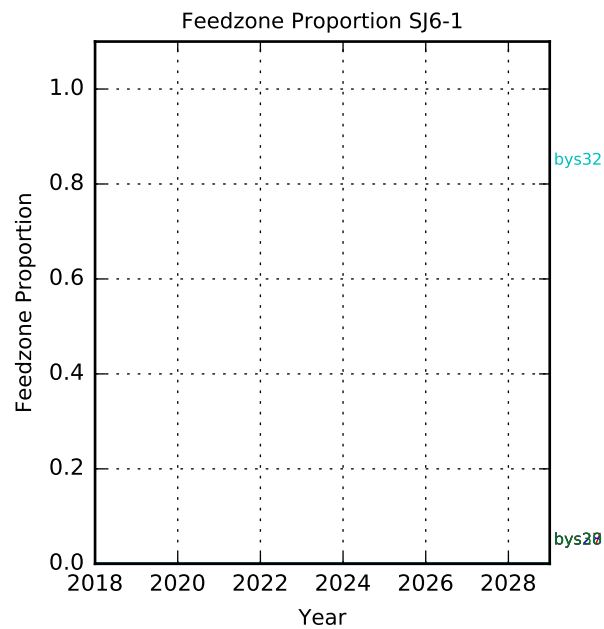
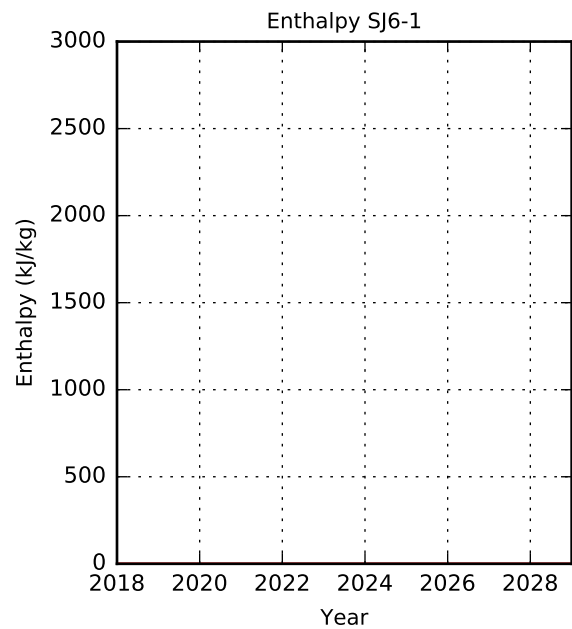
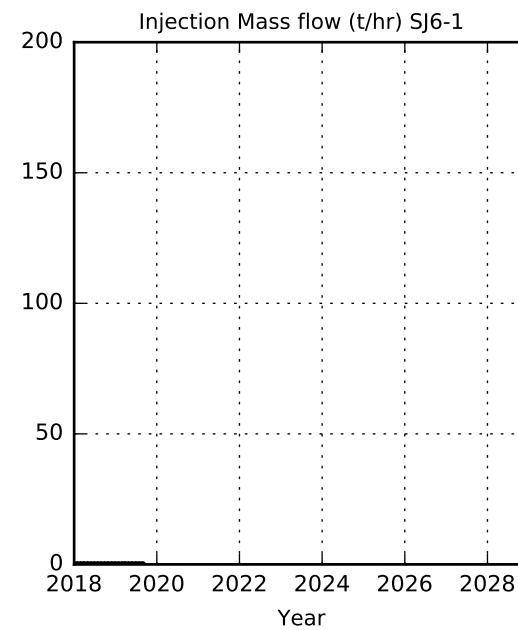
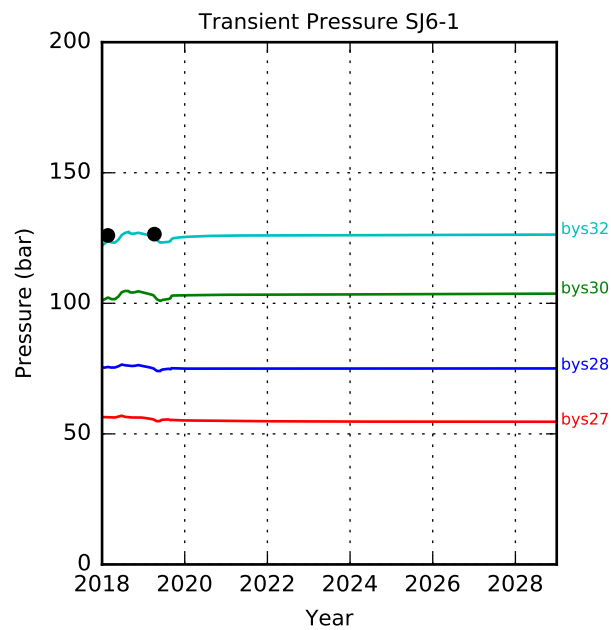
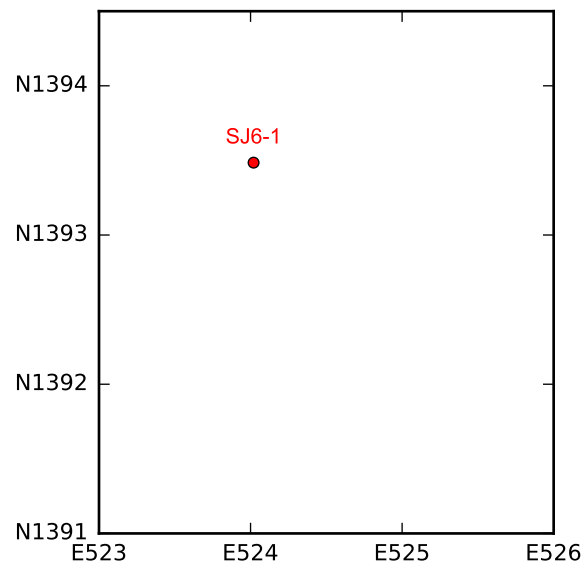


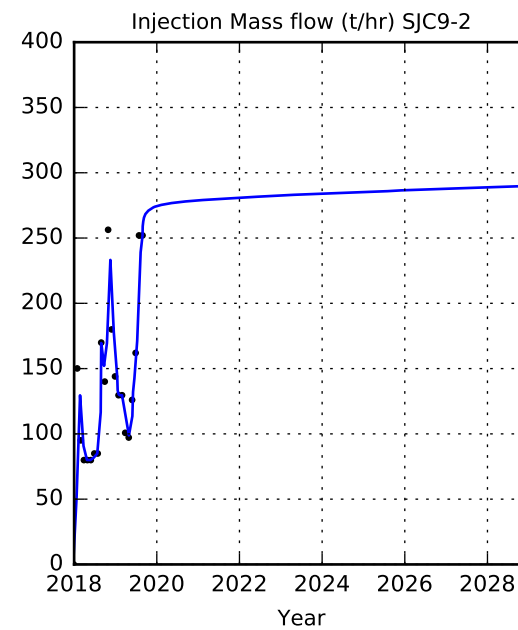
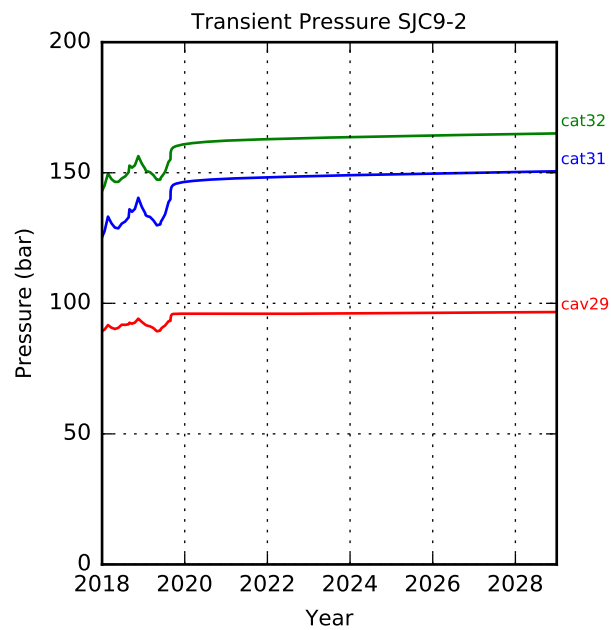
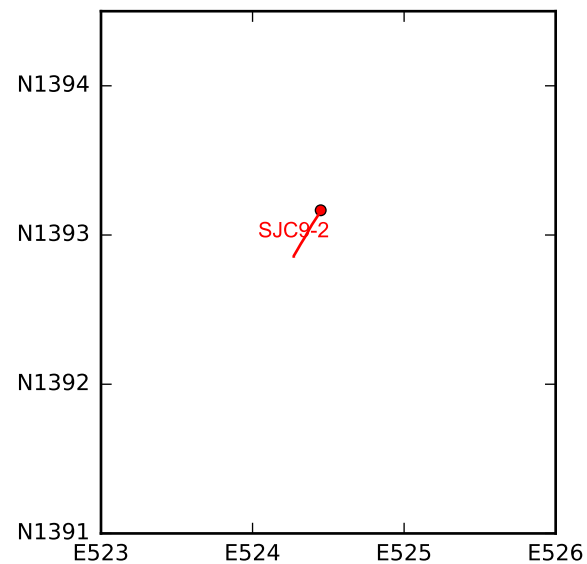




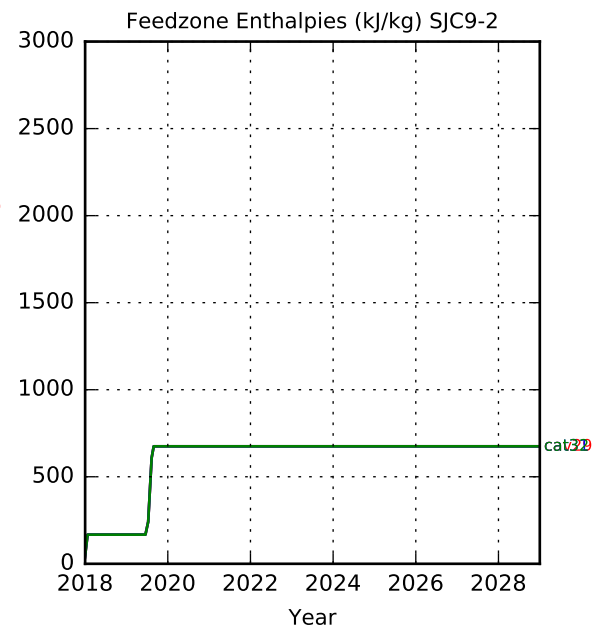
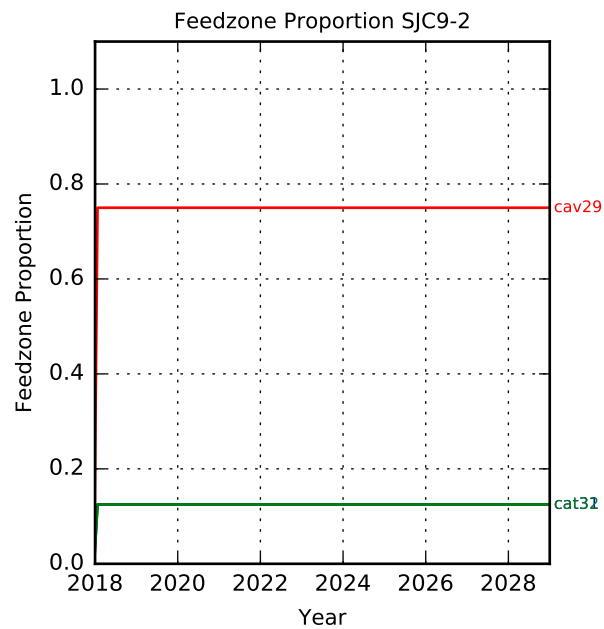
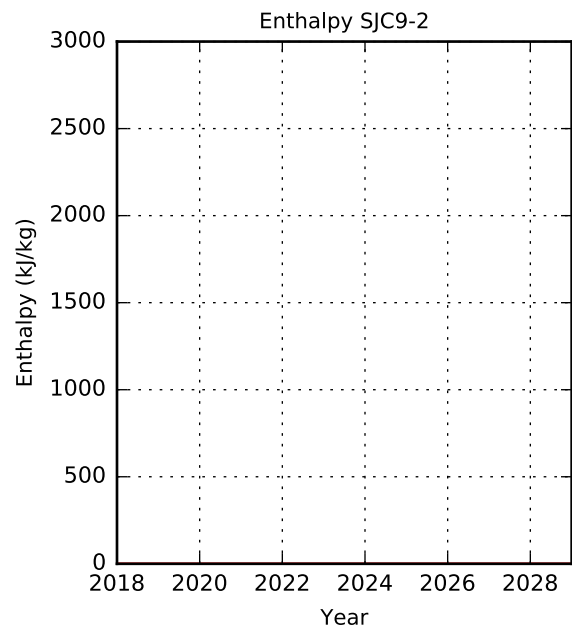
Feedzone Elevations
-2000.0 masl -1700.0 masl -1500.0 masl

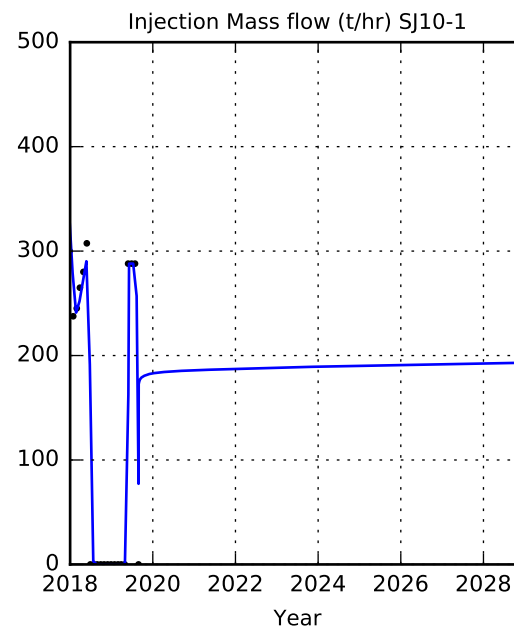
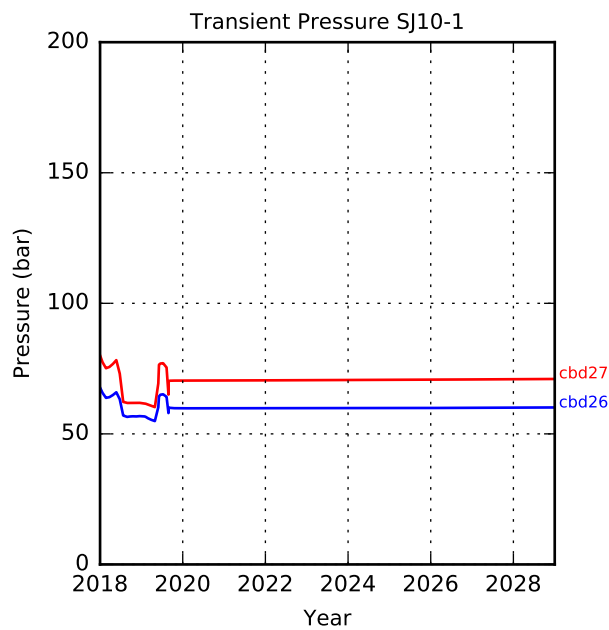
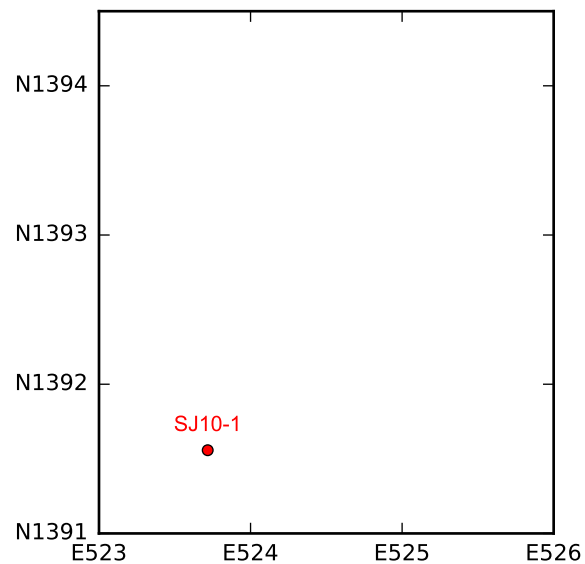




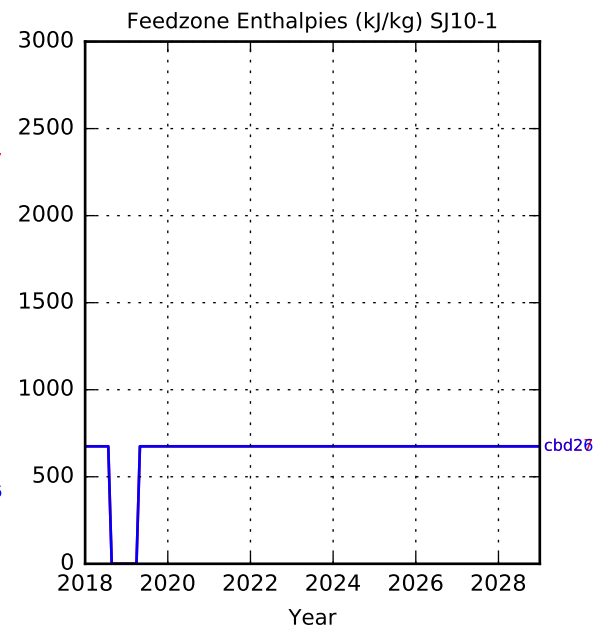
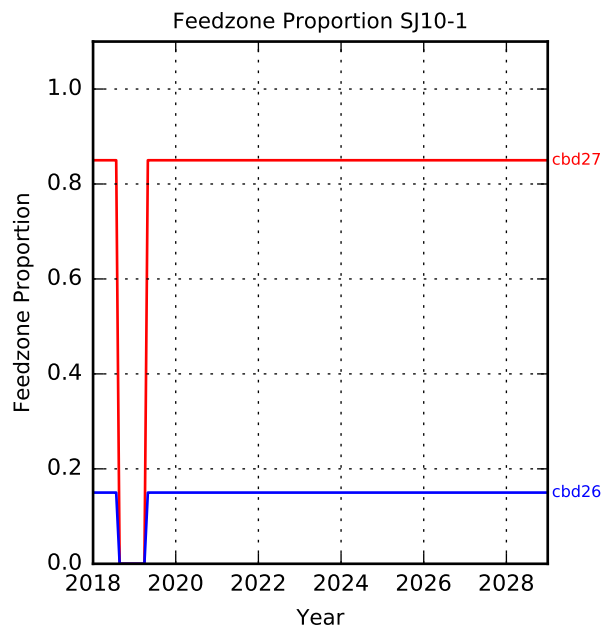
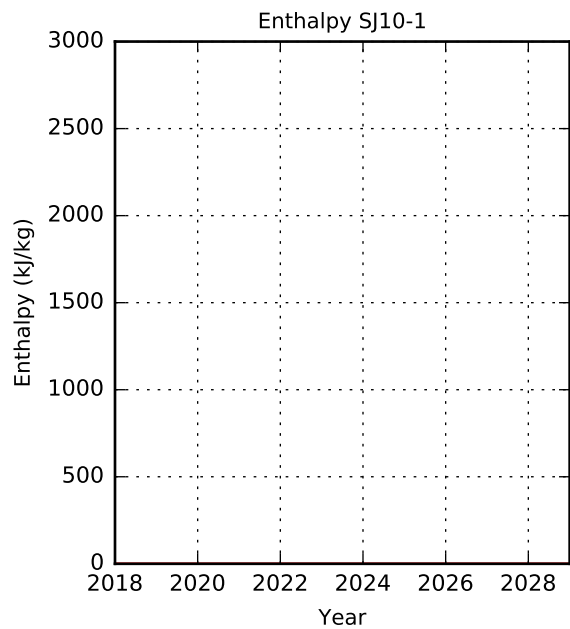


Feedzone Elevations
-1100.0 masl -1500.0 masl -1700.0 masl

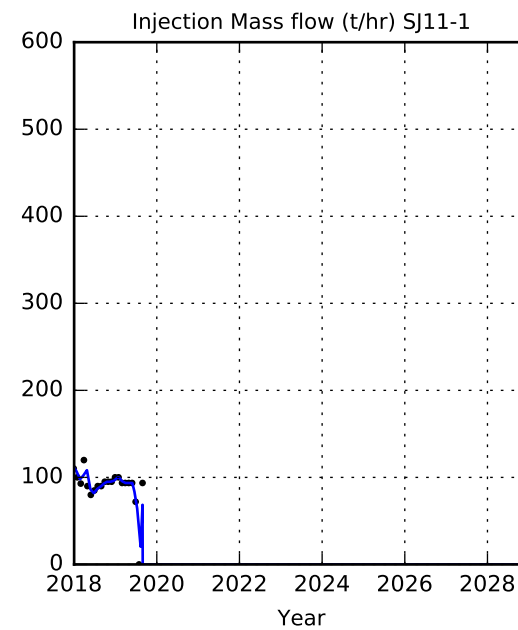
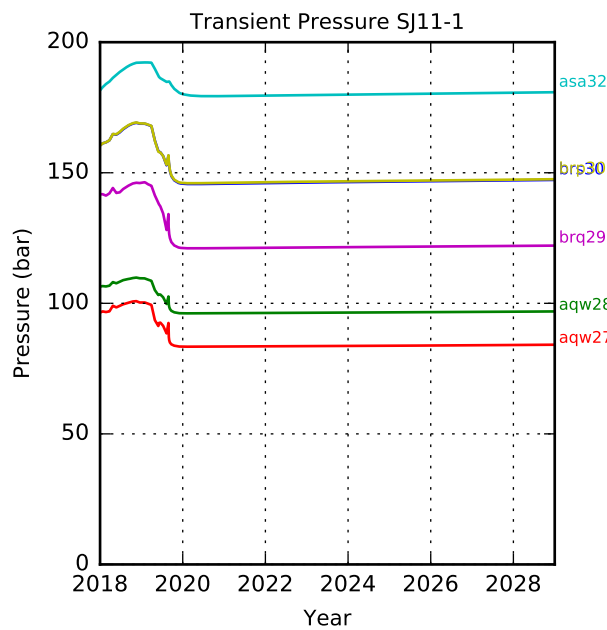
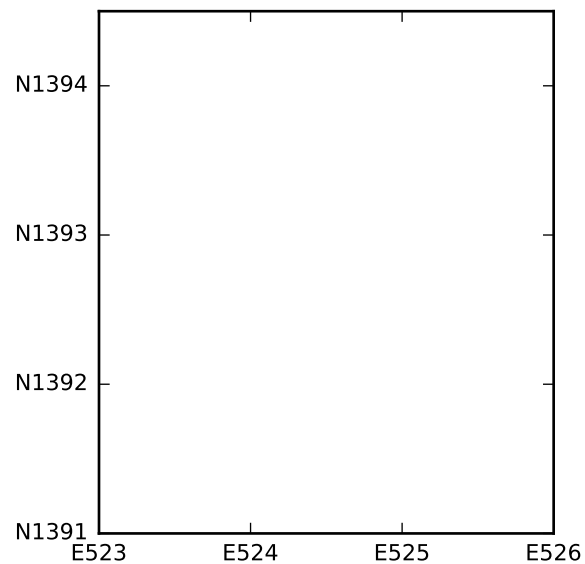




Feedzone Elevations
-700.0 masl -525.0 masl

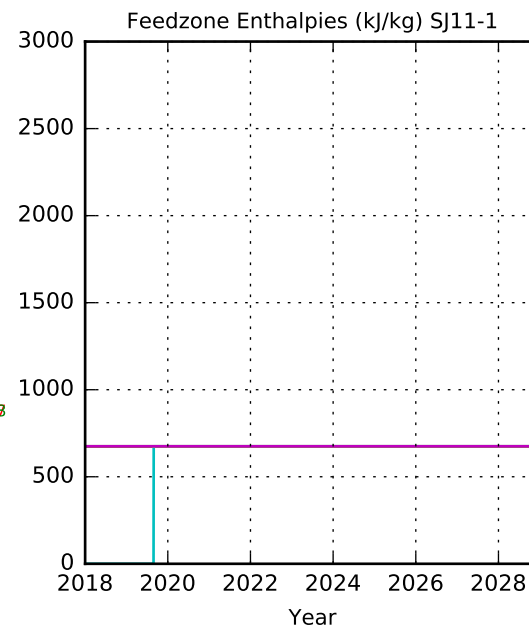
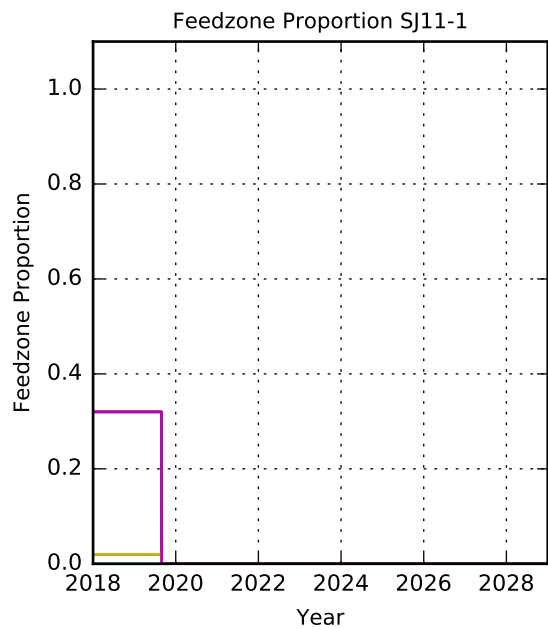
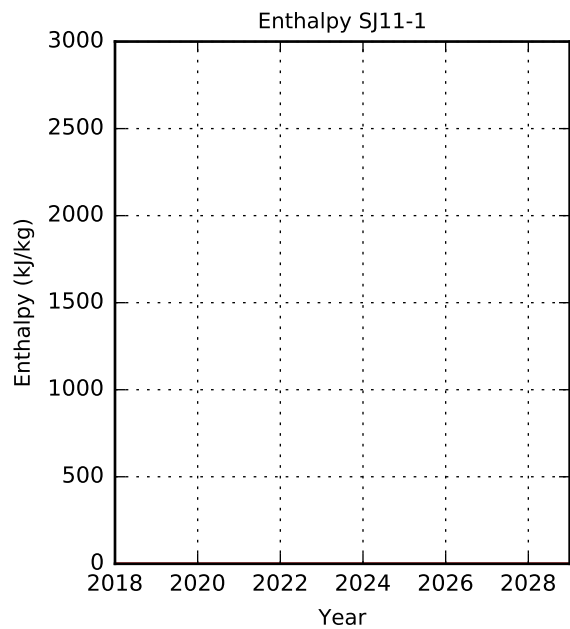


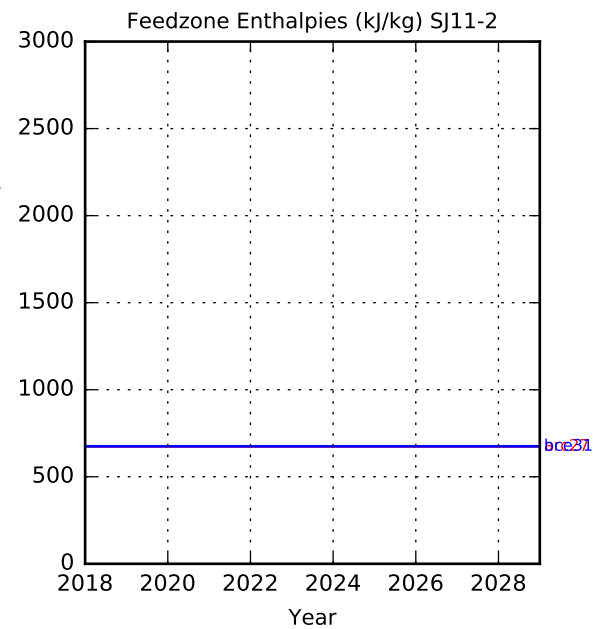
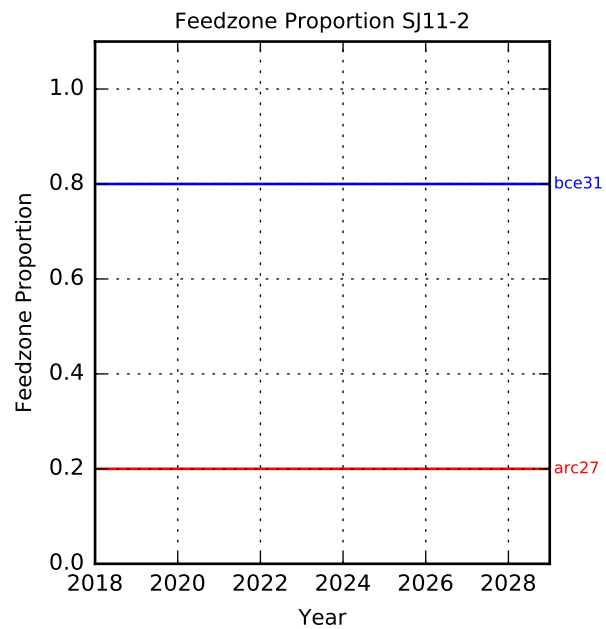
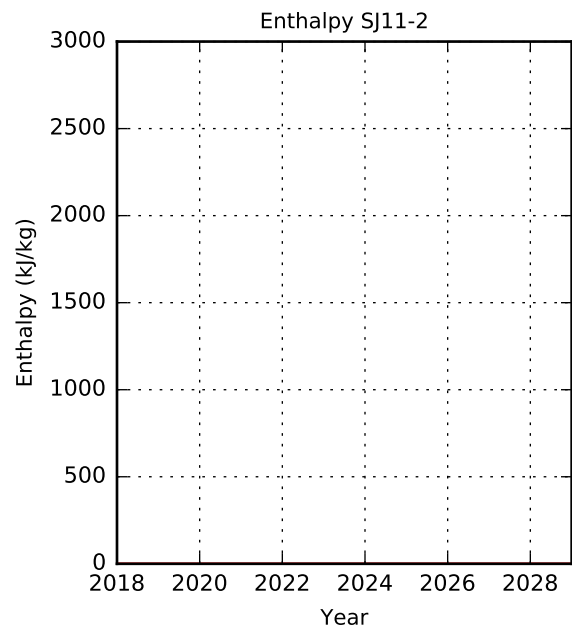
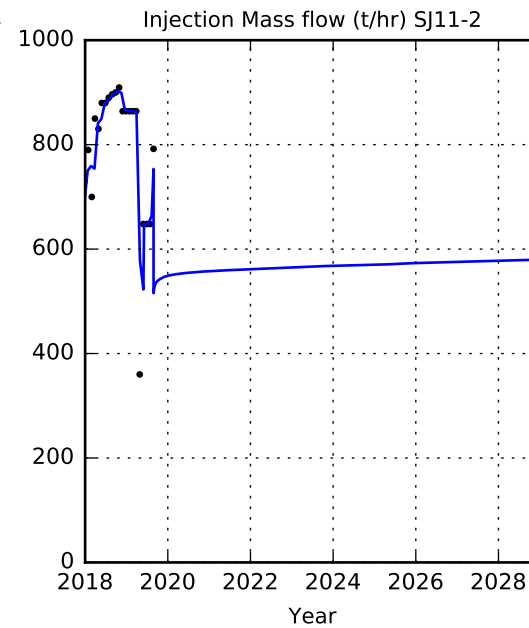
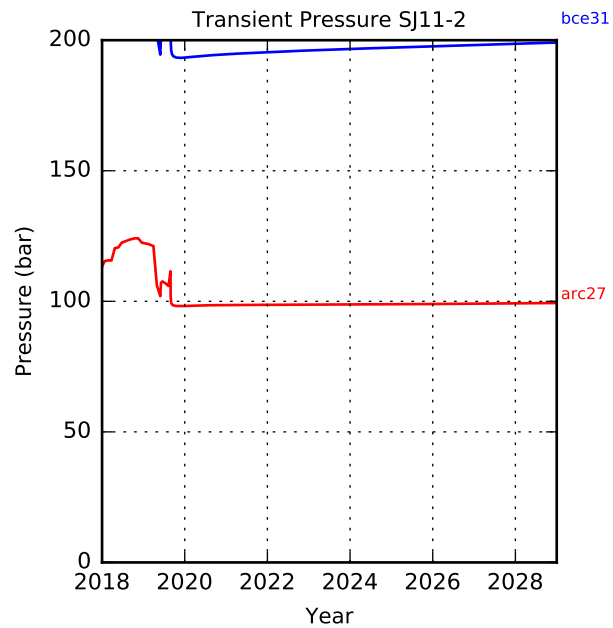
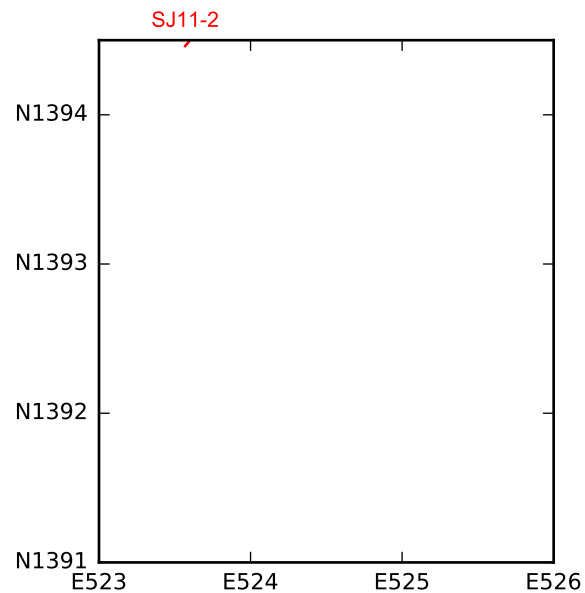
SJ11-1

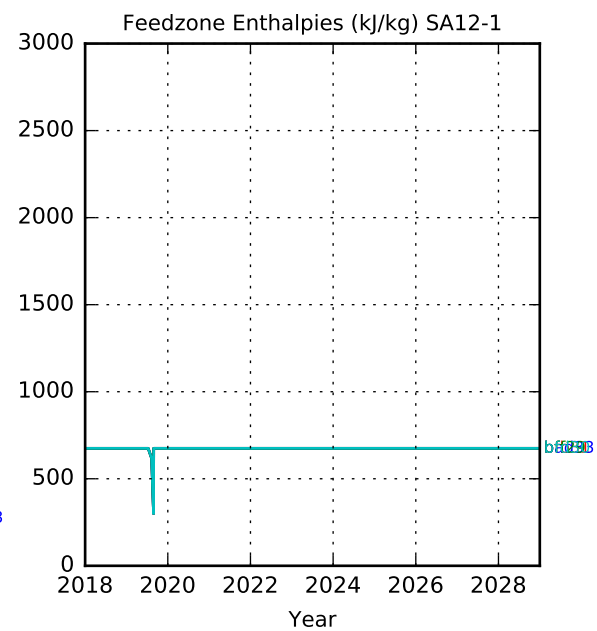
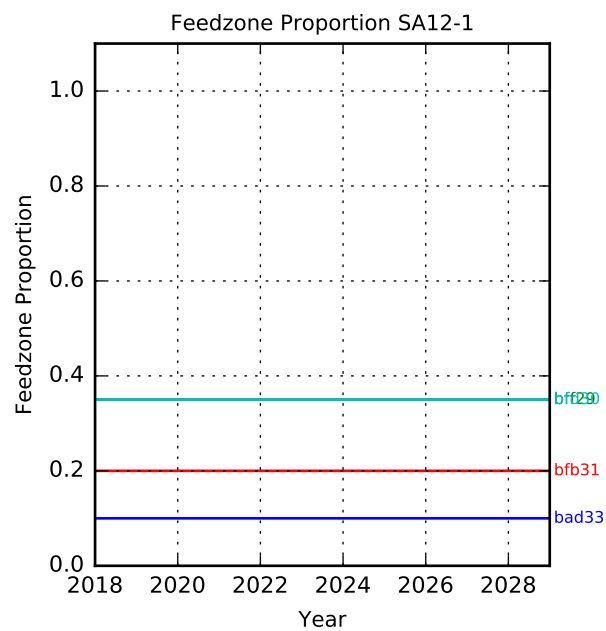
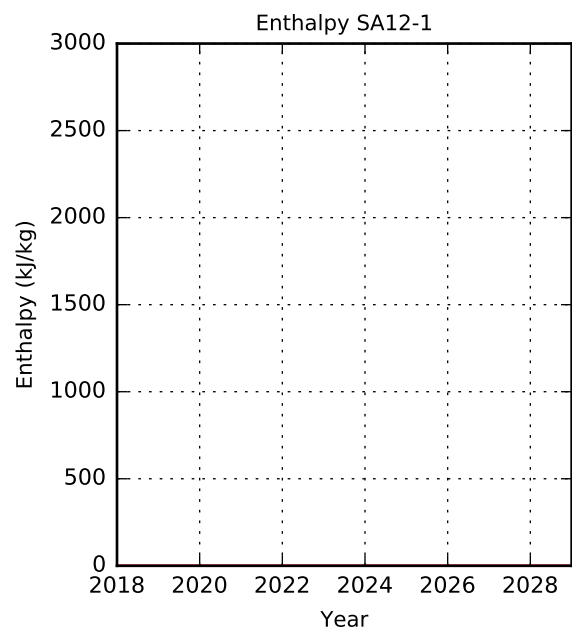
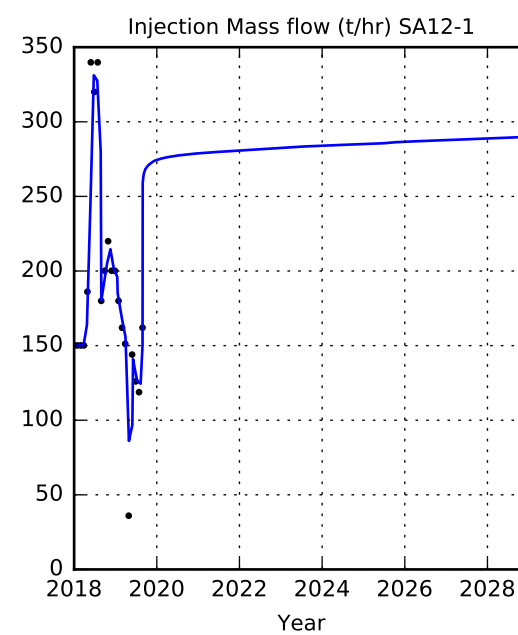
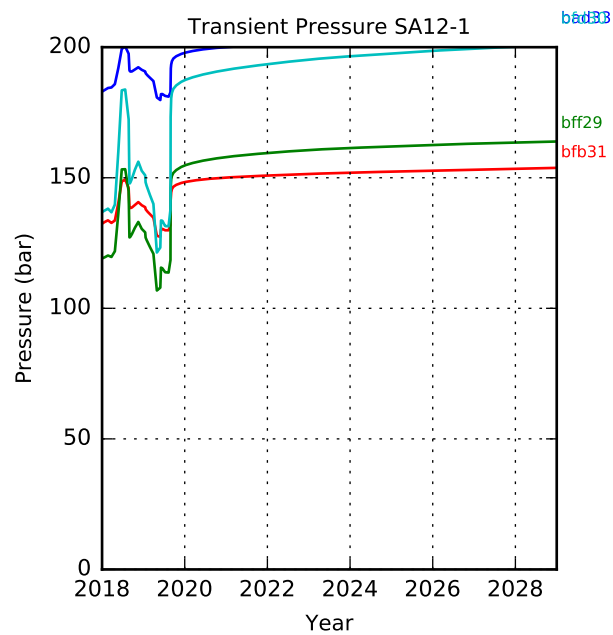
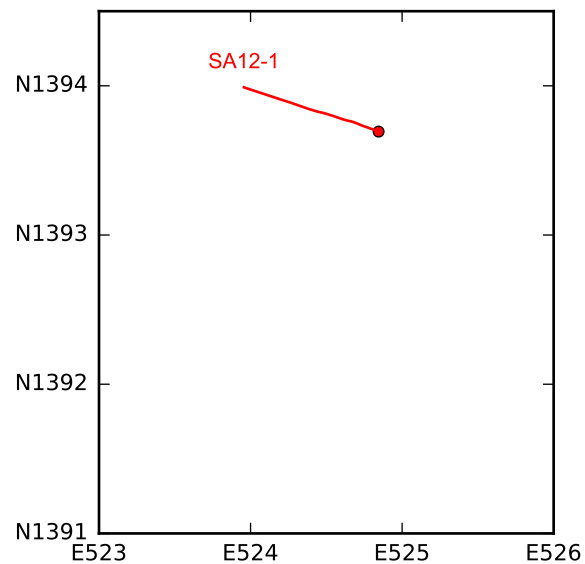


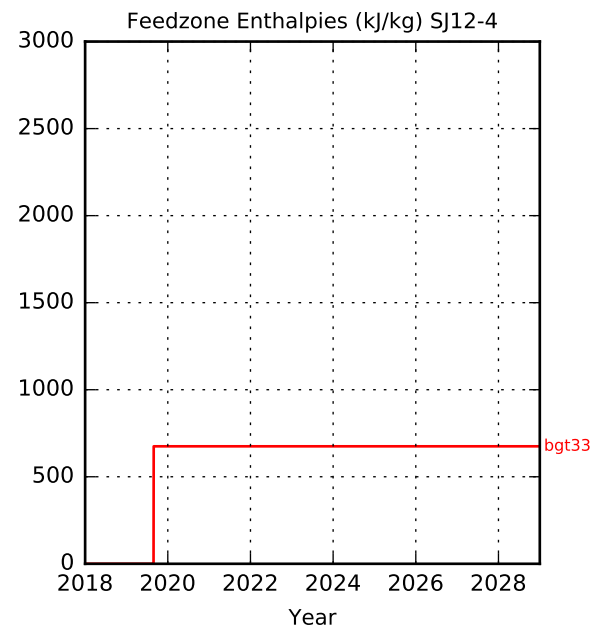
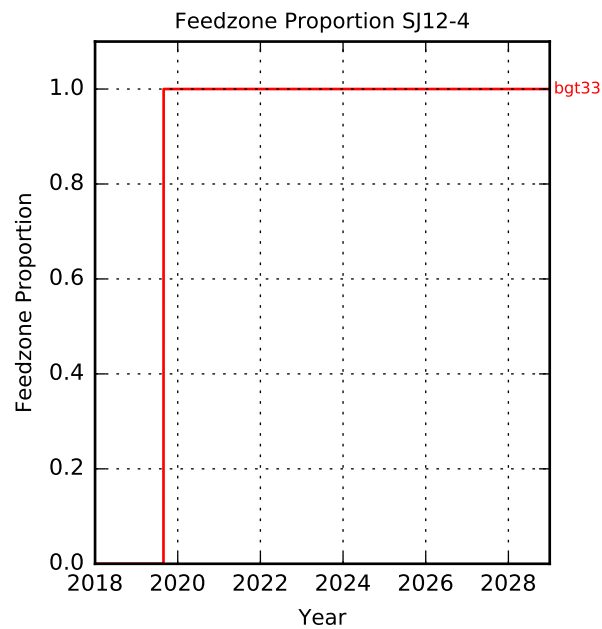
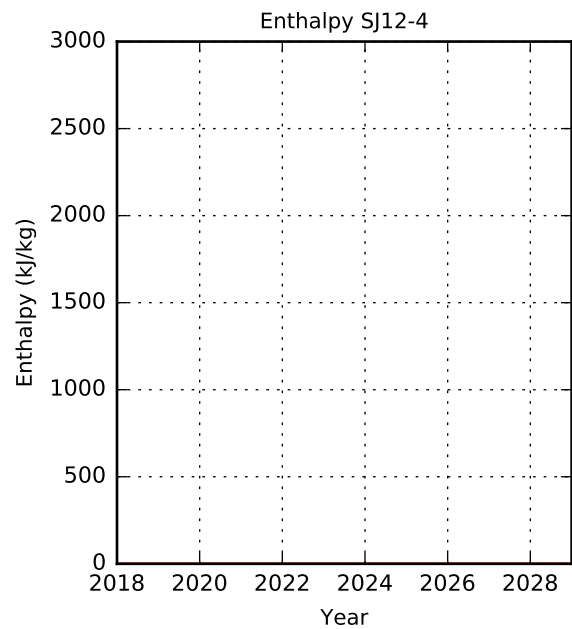
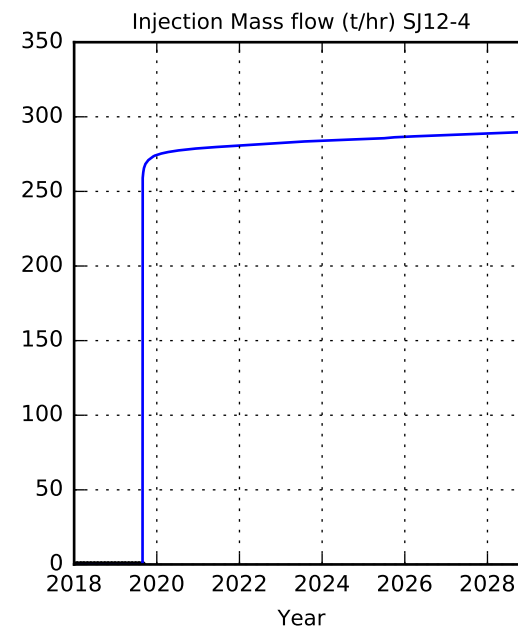
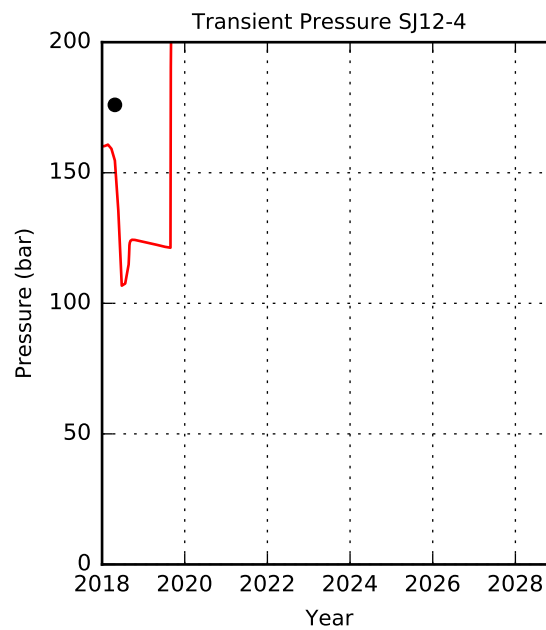
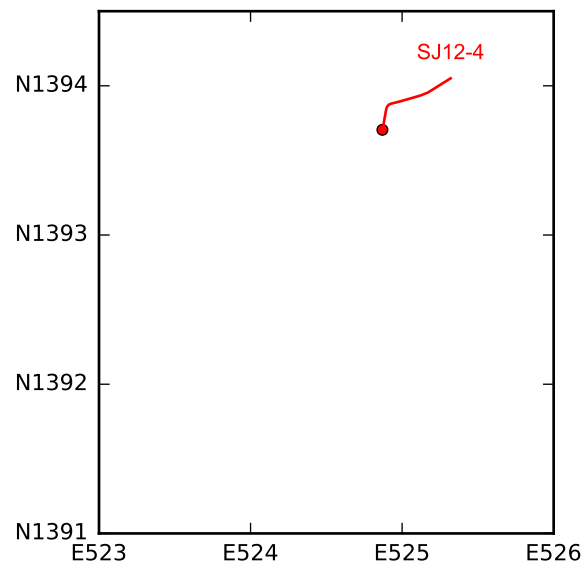
Feedzone Elevations

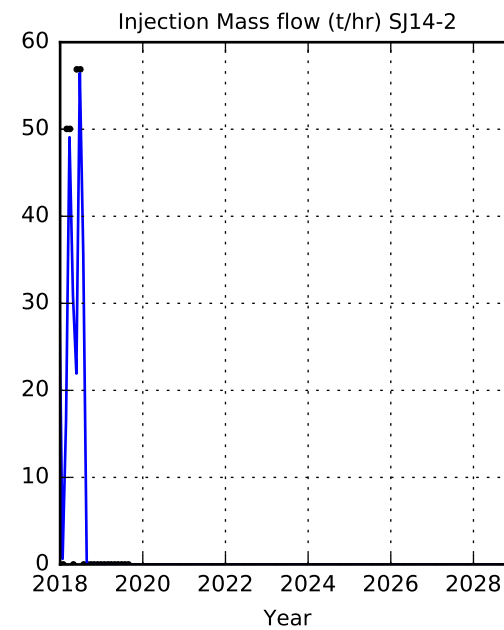
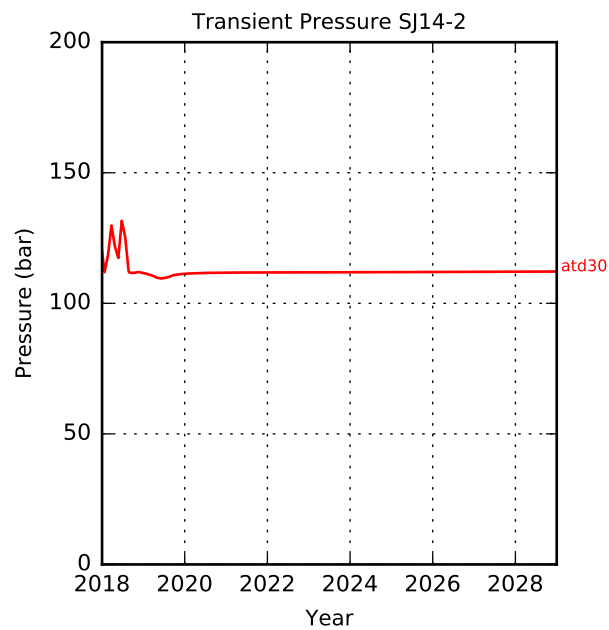
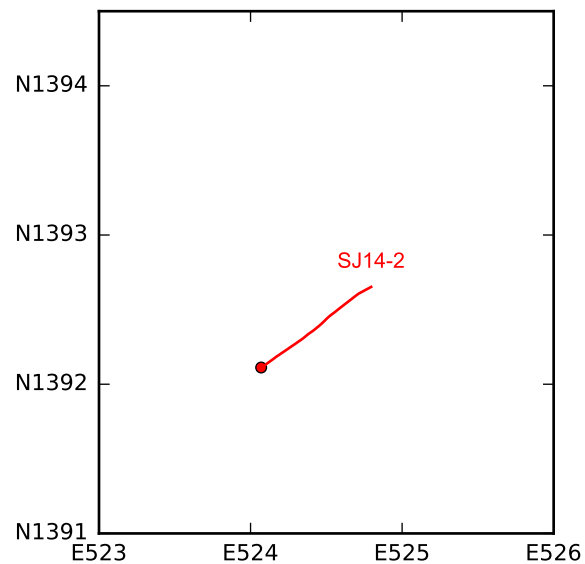
-700.0 masl -1300.0 masl -900.0 masl
-1700.0 masl -1300.0 masl -1100.0 masl



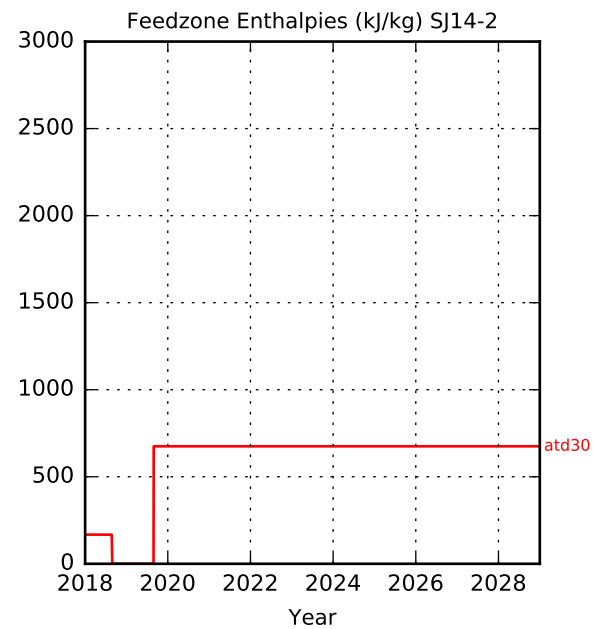
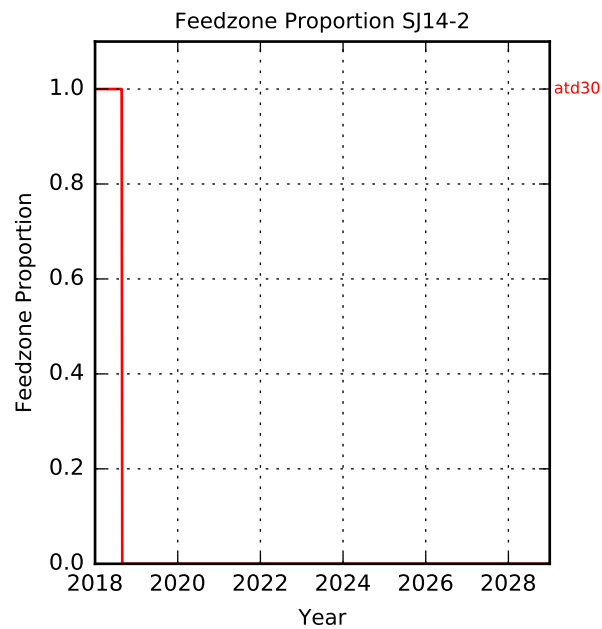
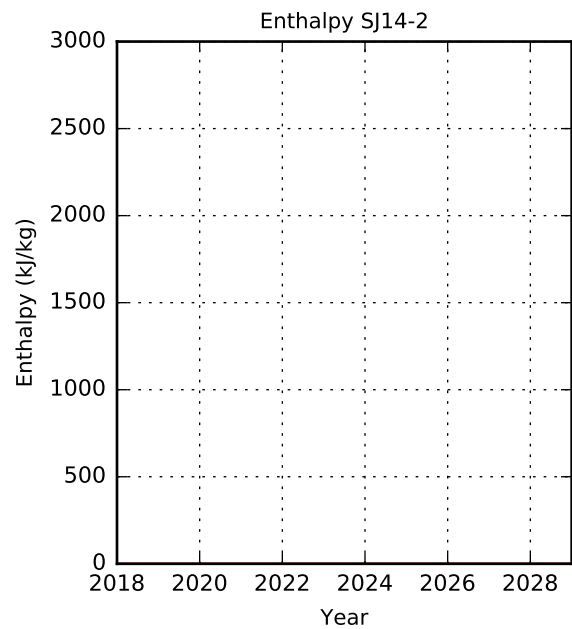


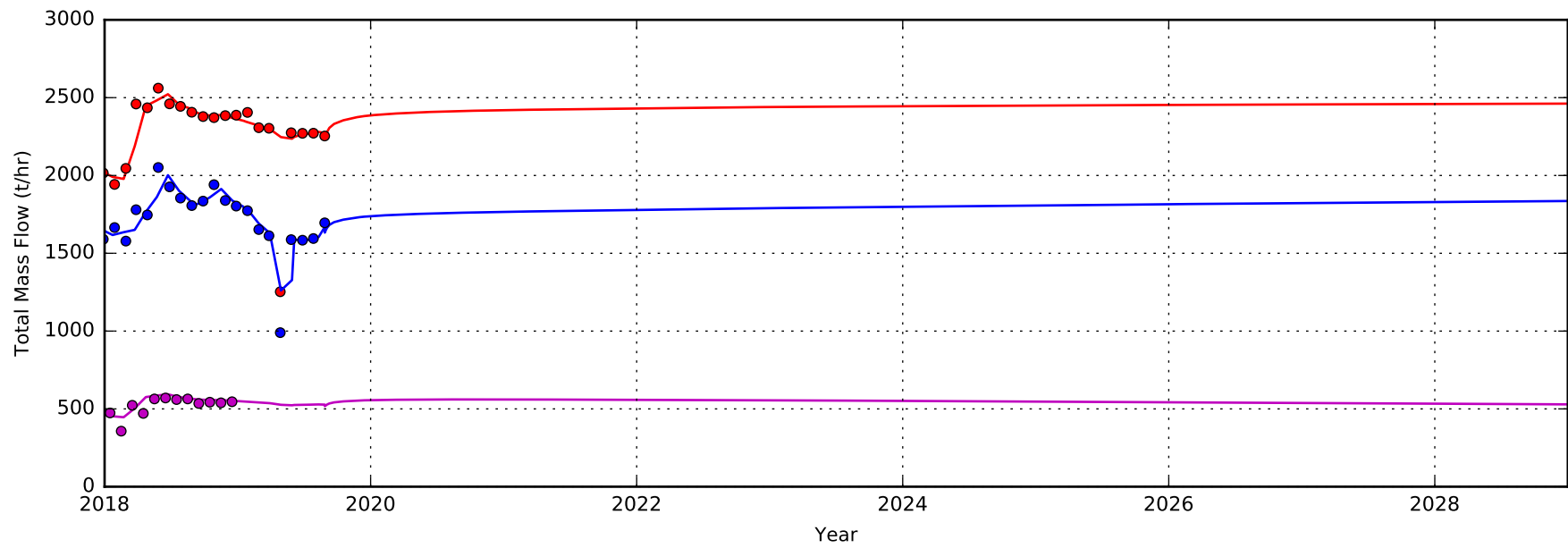




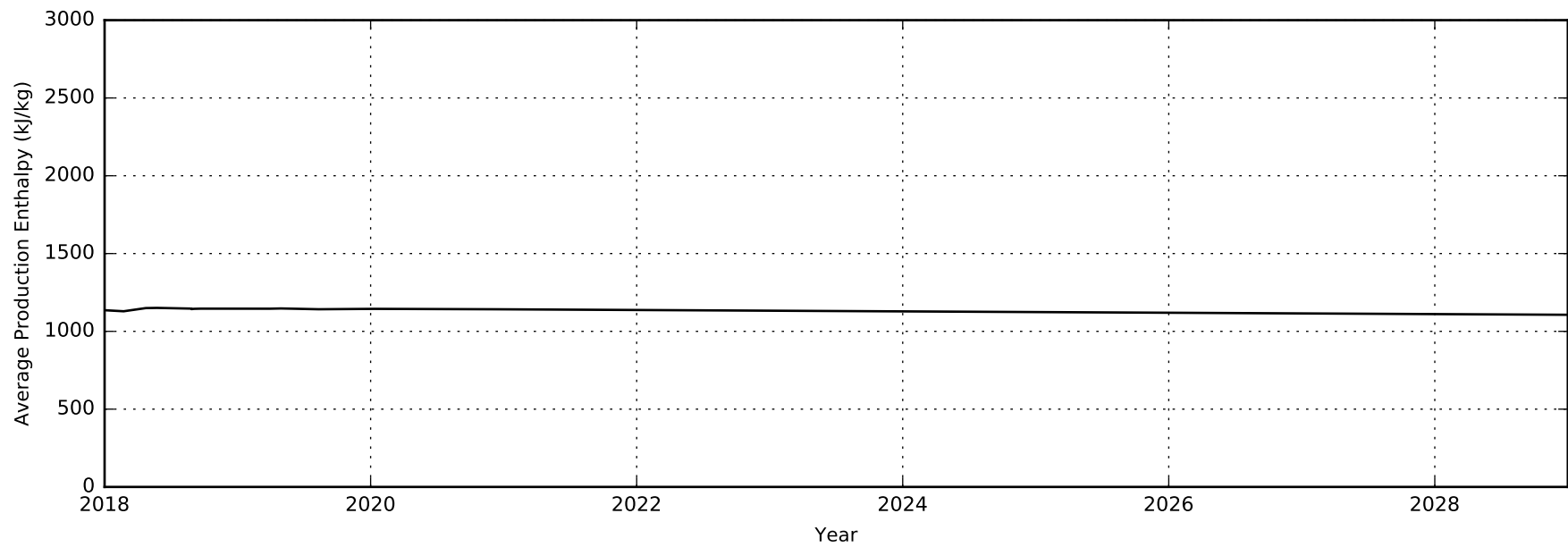


Feedzone Elevations
-1300.0 masl

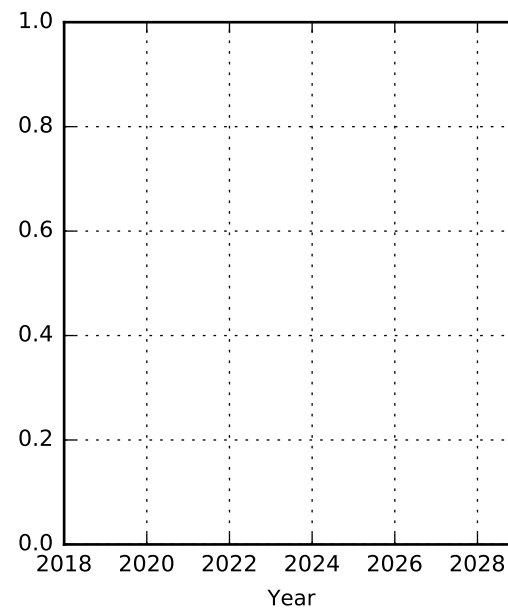
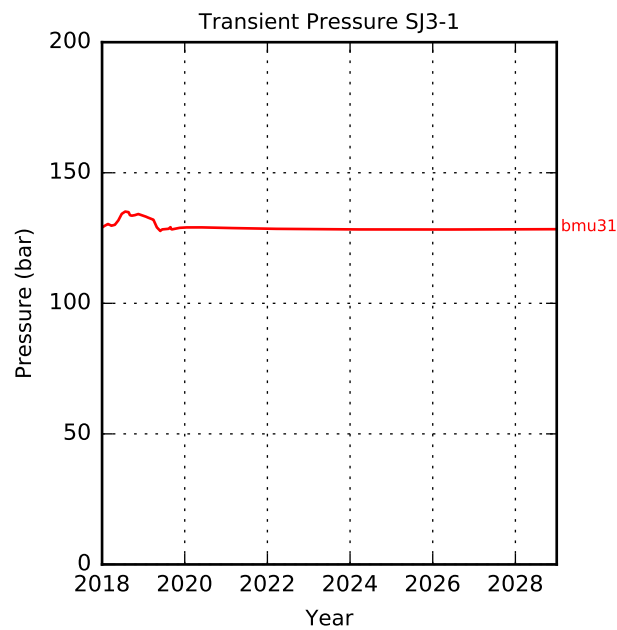
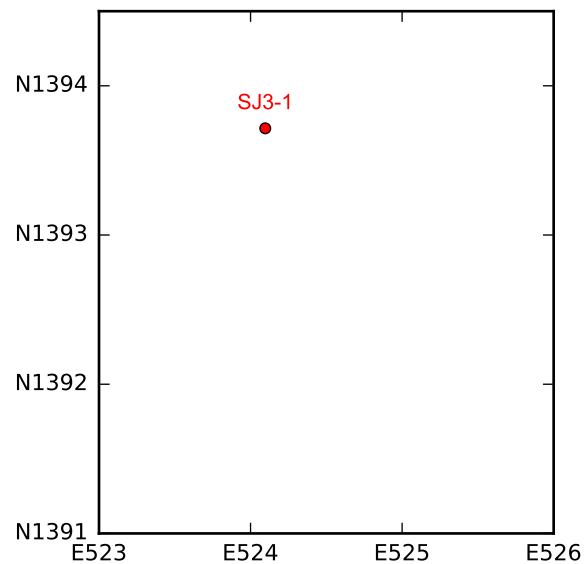




— Total Production — Total Steam — Total Reinjection

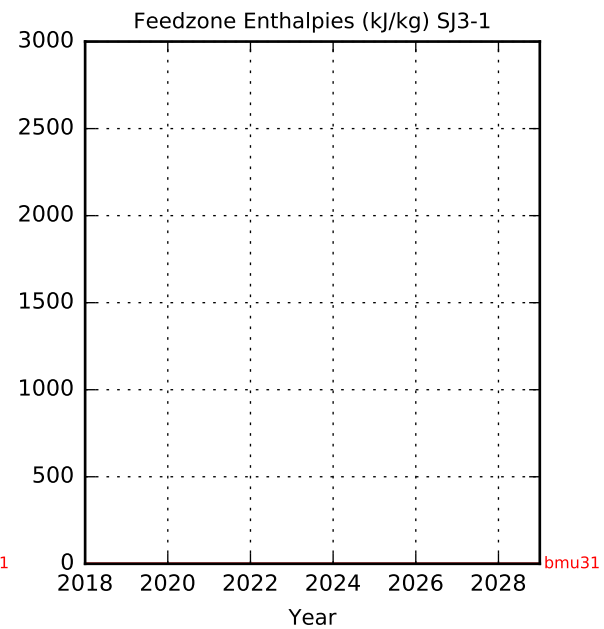
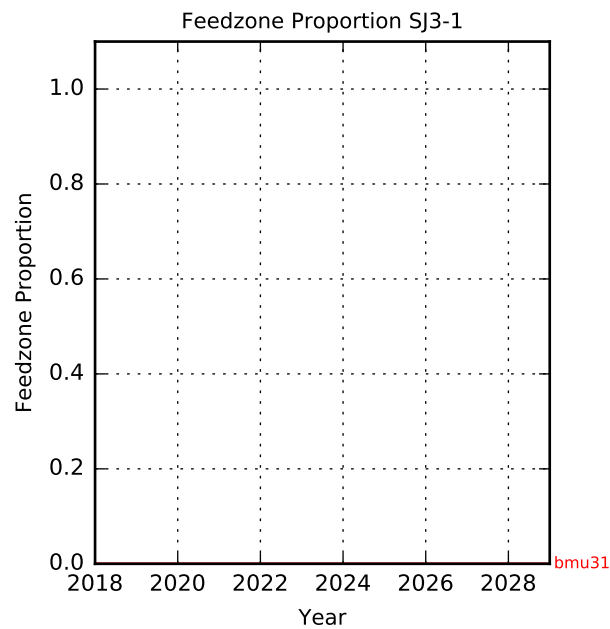
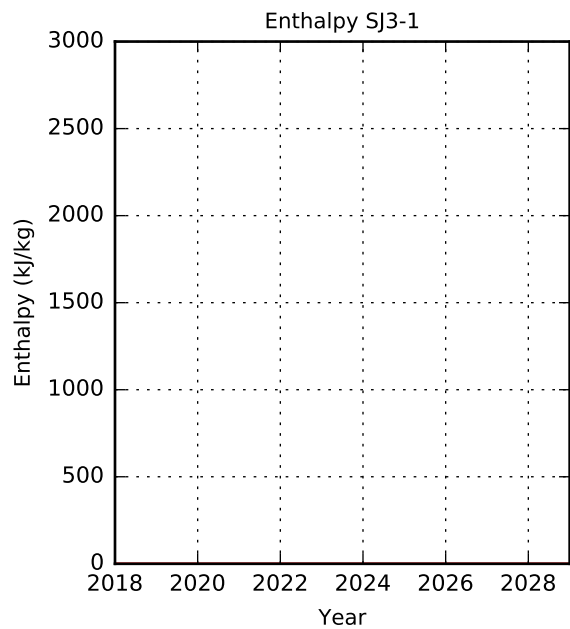


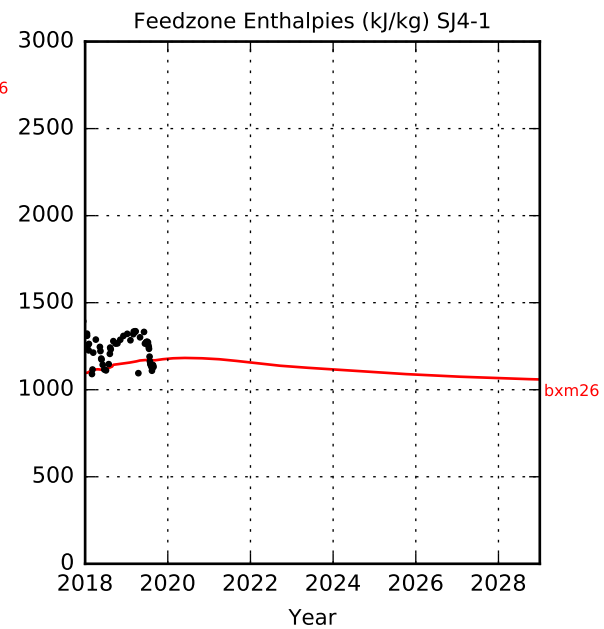
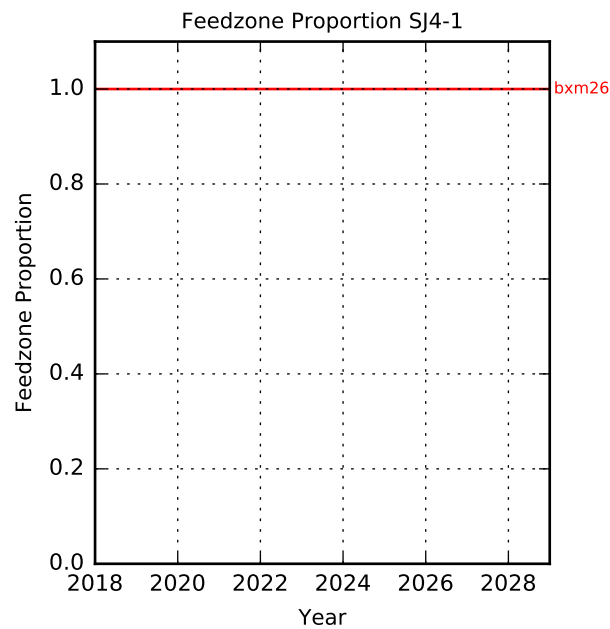
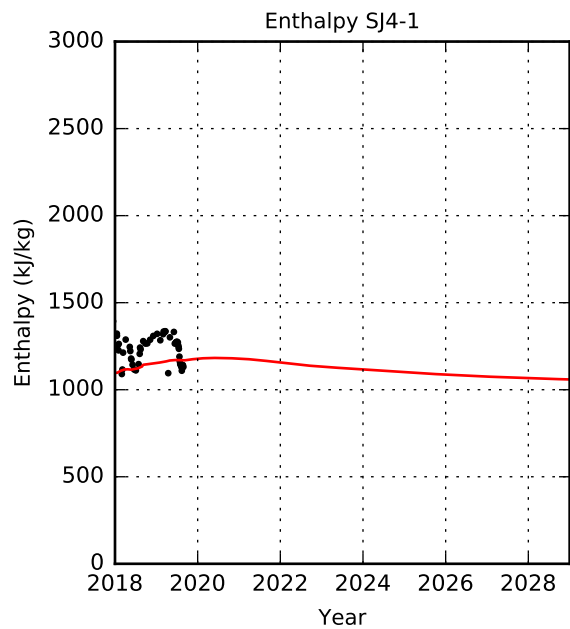
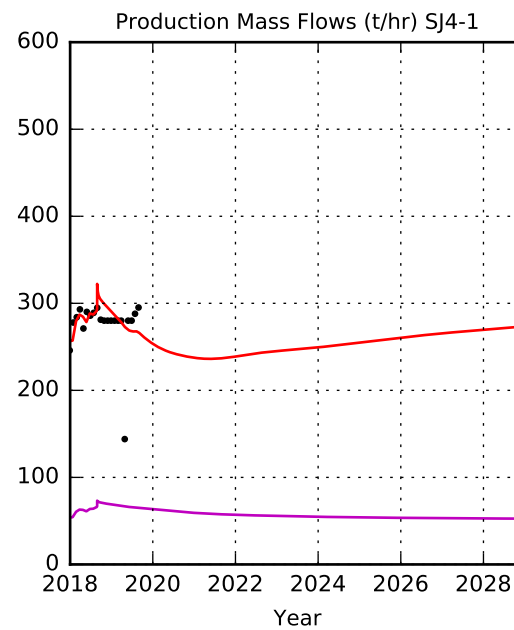
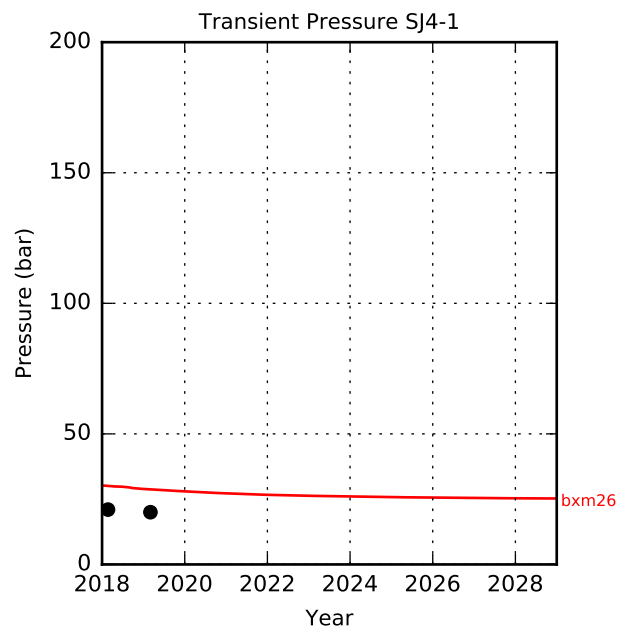
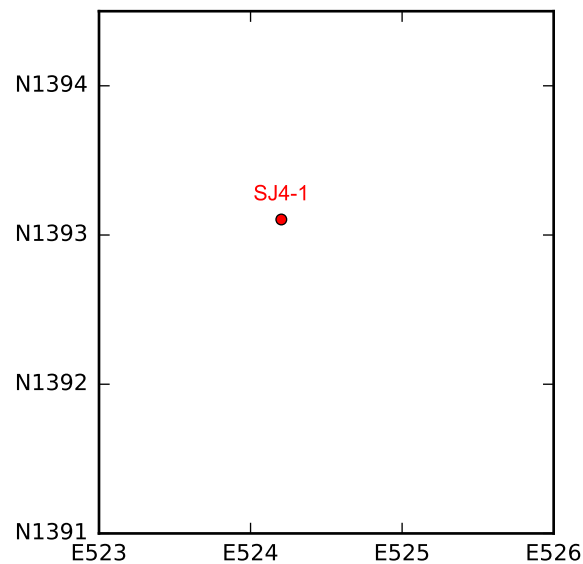
Appendix E. Future Scenario 003 Results

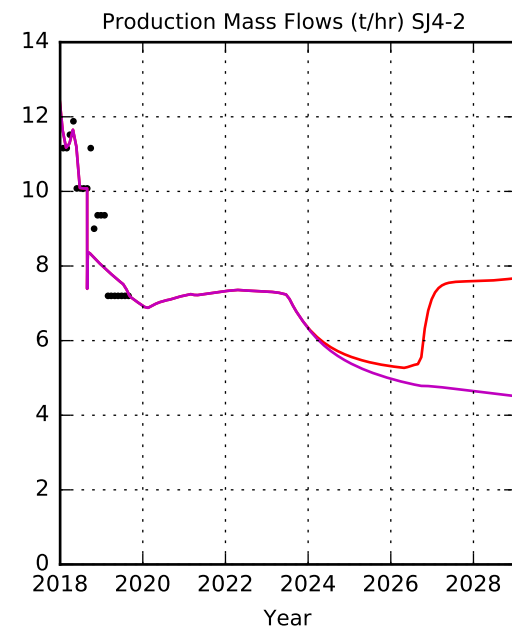
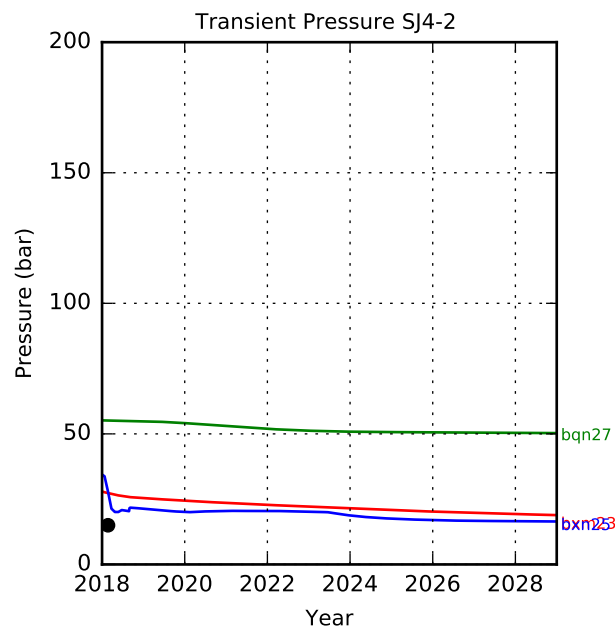
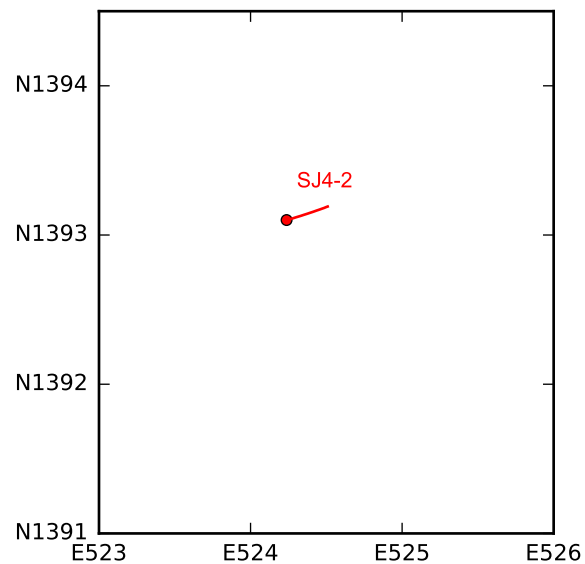


Feedzone Elevations

-1500.0 masl

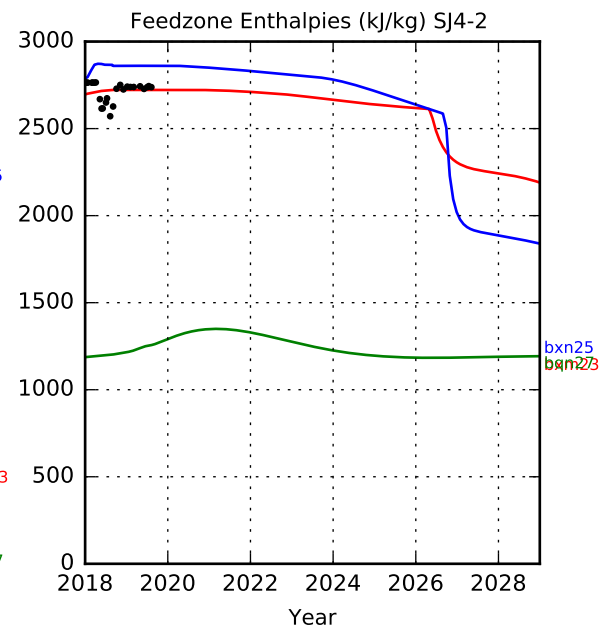
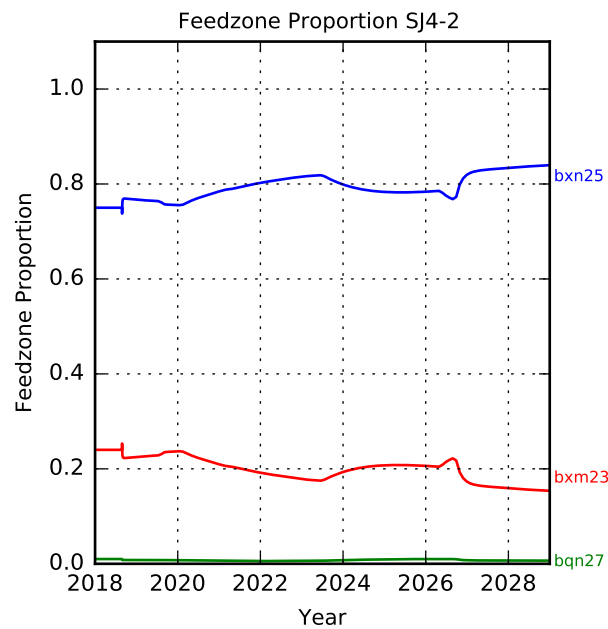
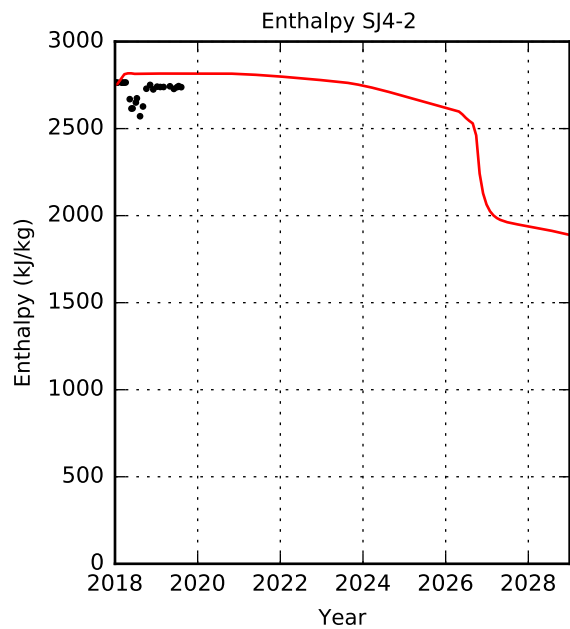


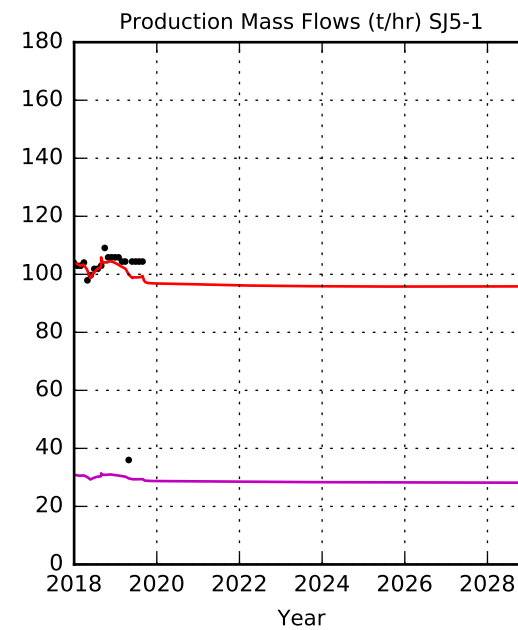
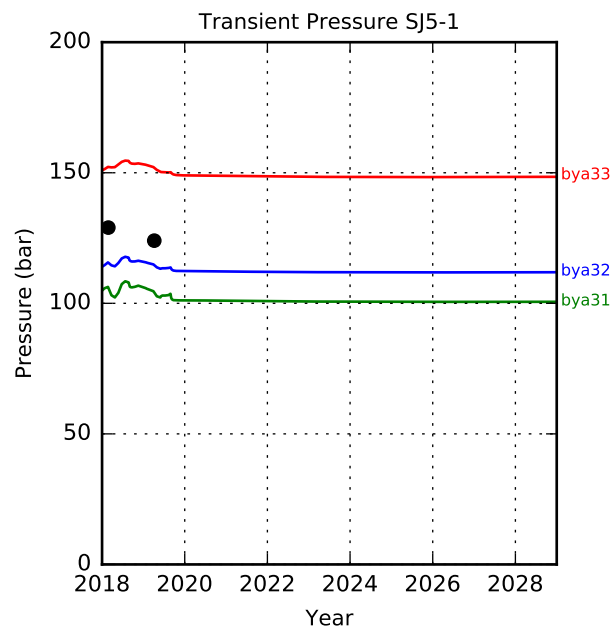
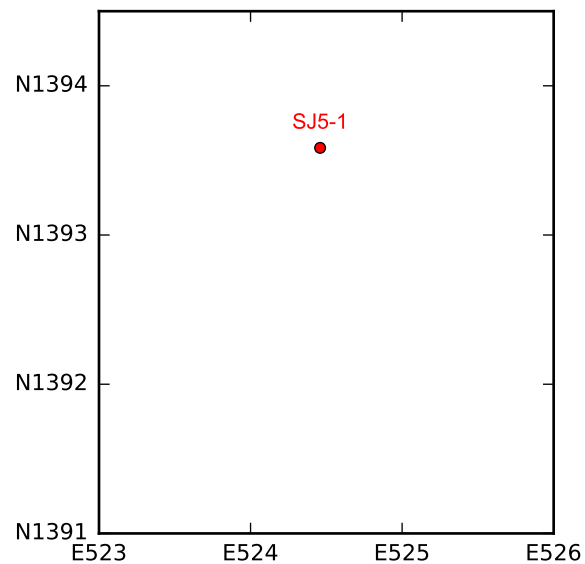




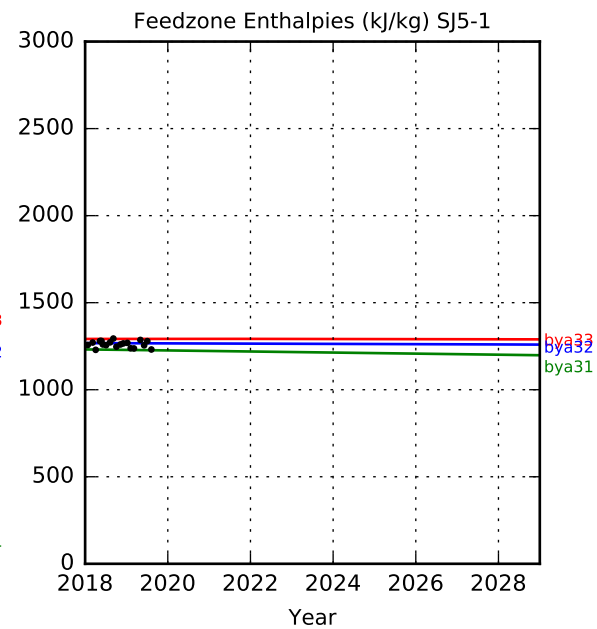
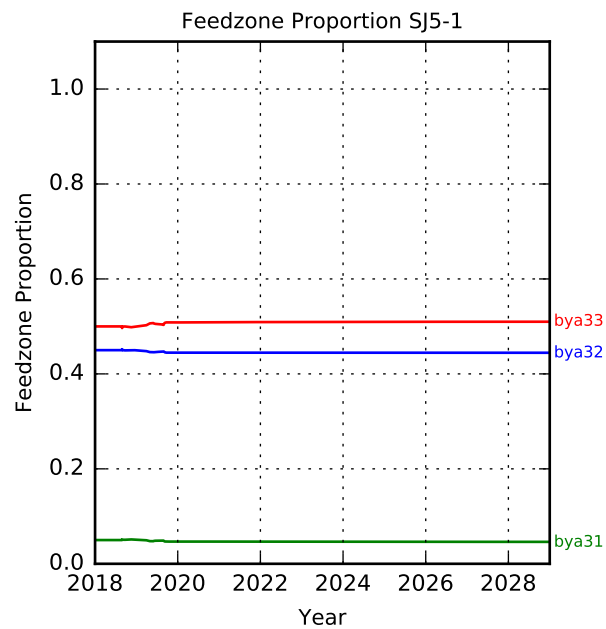
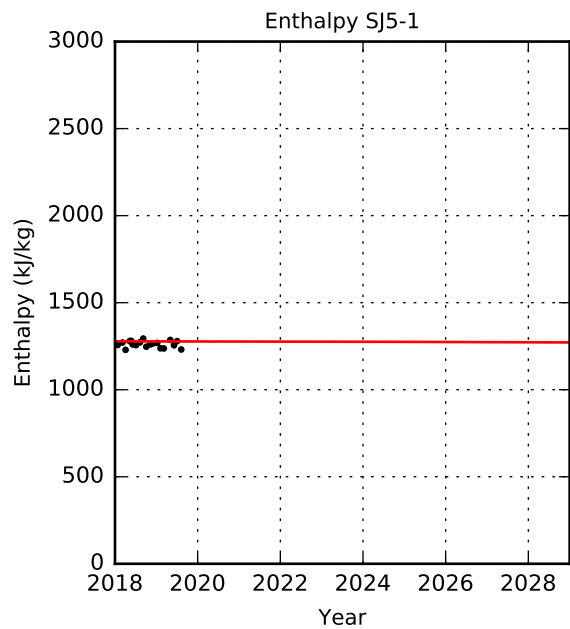
Feedzone Elevations
-150.0 masl -375.0 masl -700.0 masl

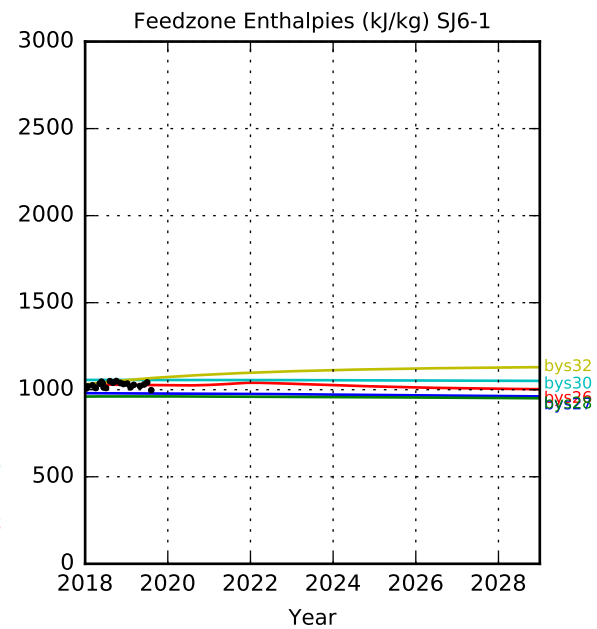
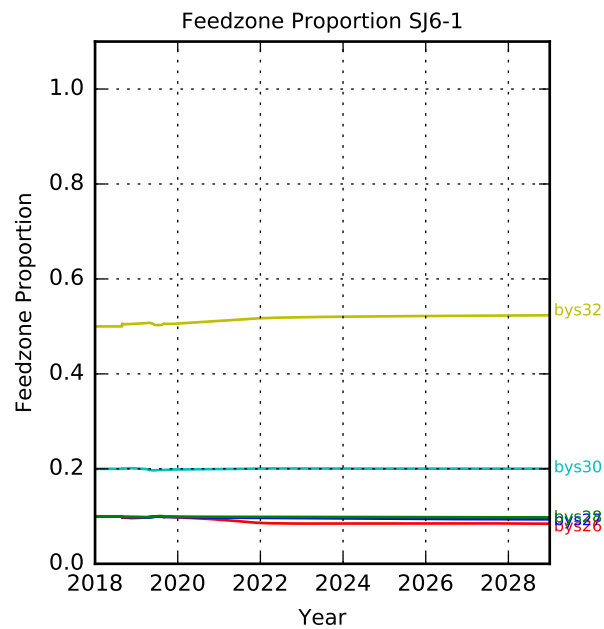
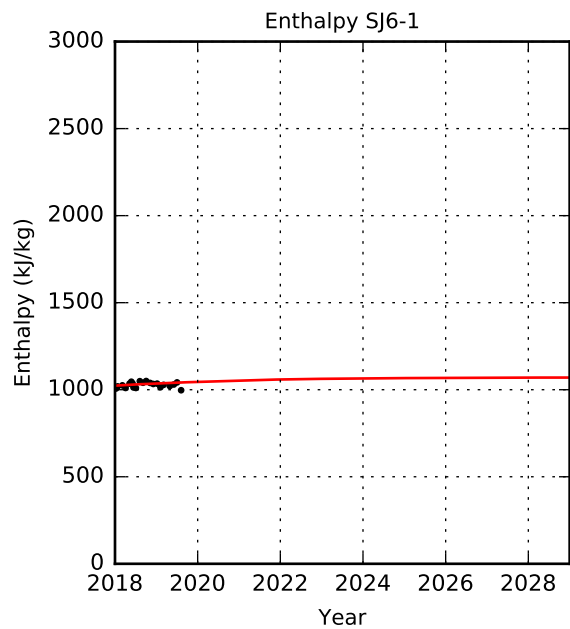
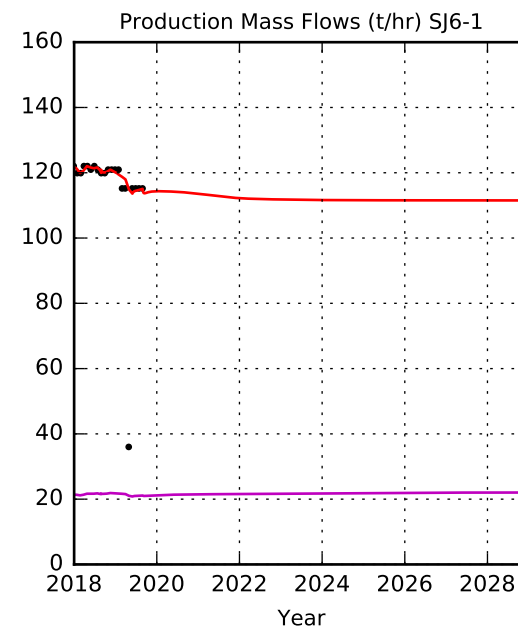
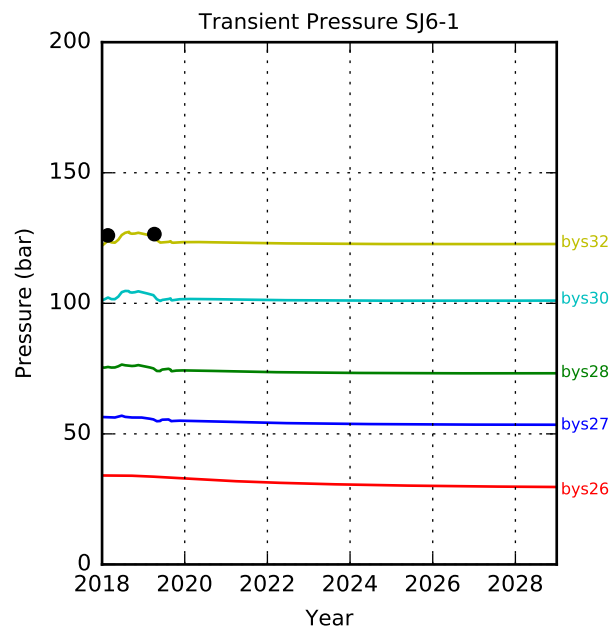
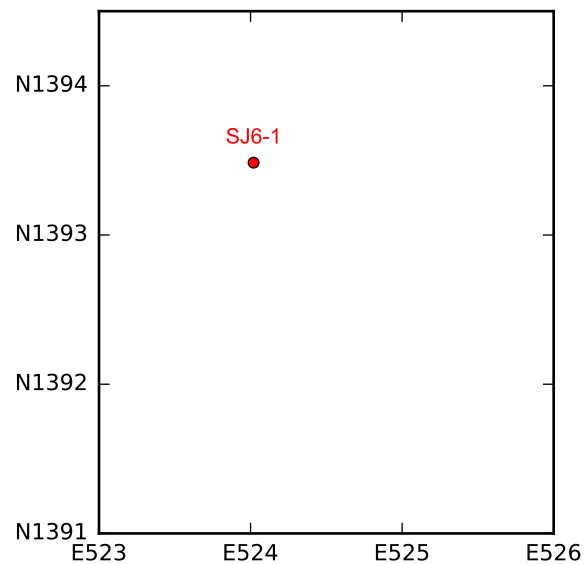
— Total Mass Flow — Steam Flow

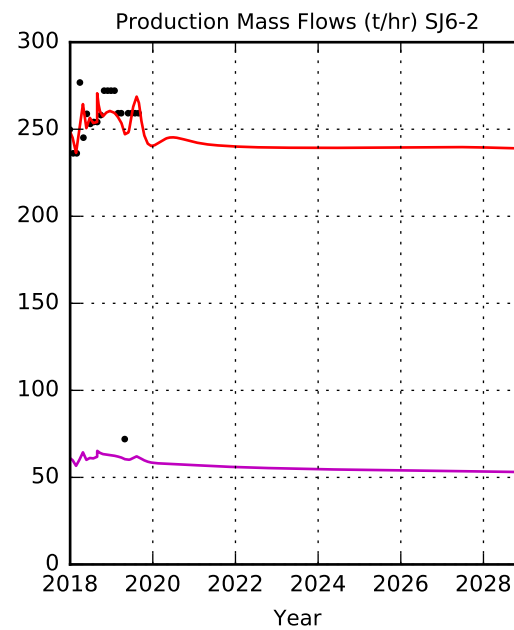
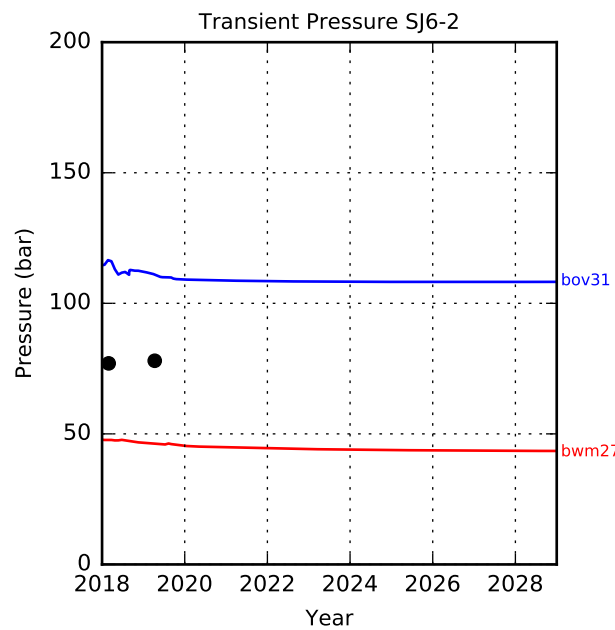
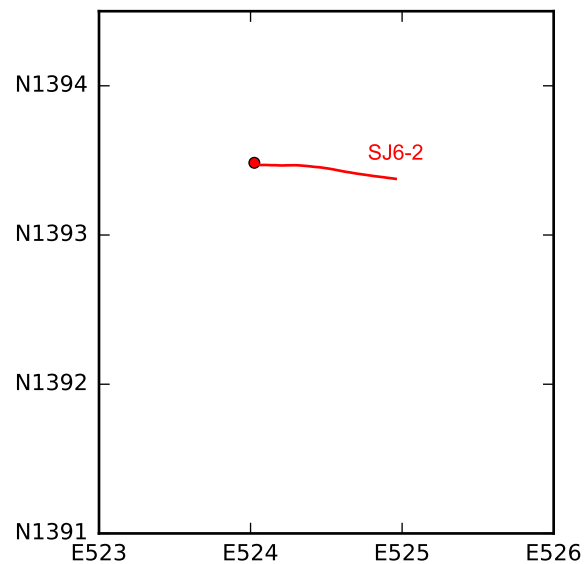




Feedzone Elevations
-2000.0 masl -1700.0 masl -1500.0 masl

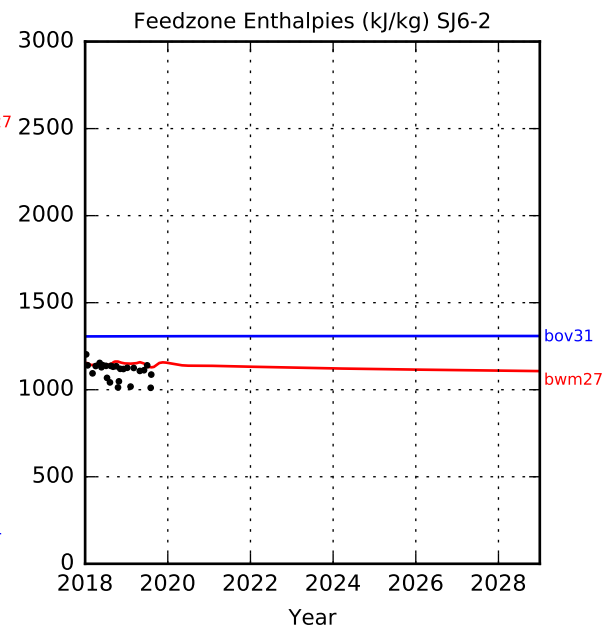
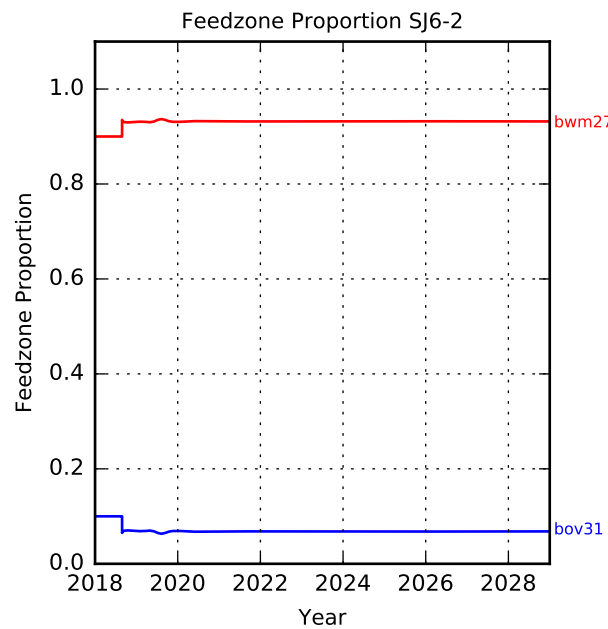
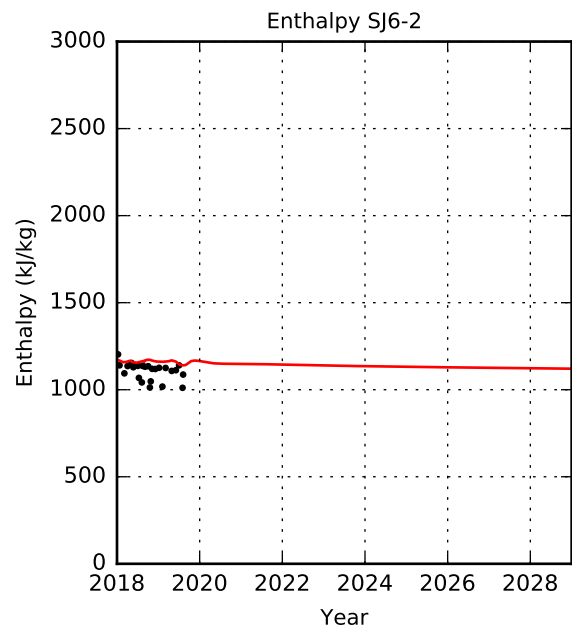


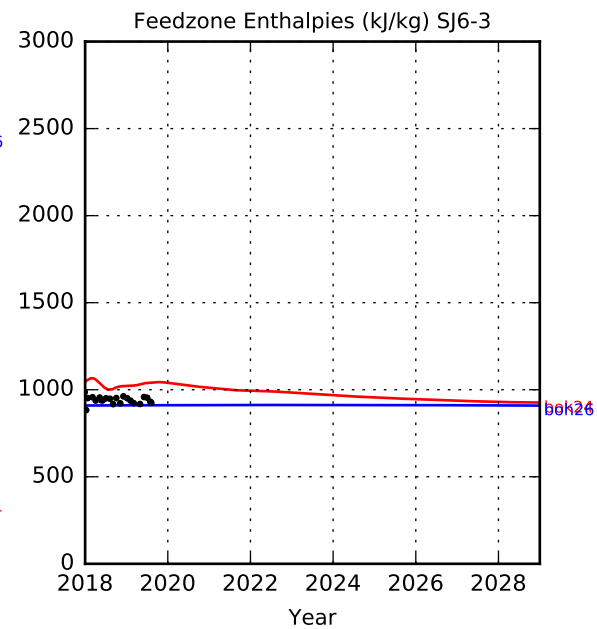
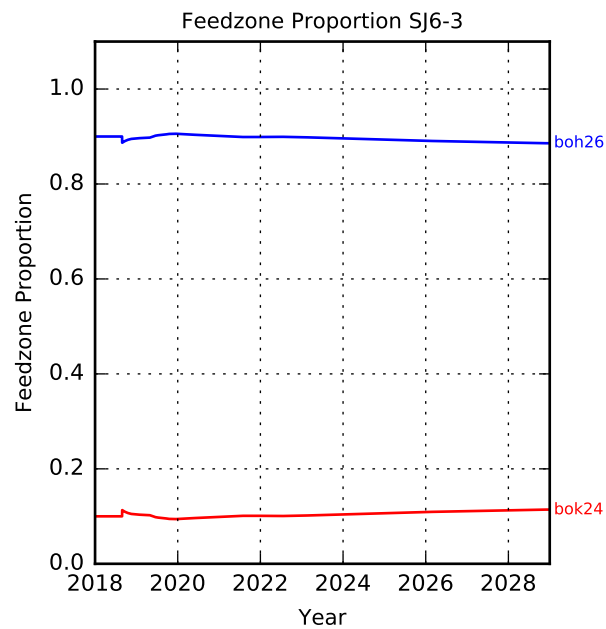
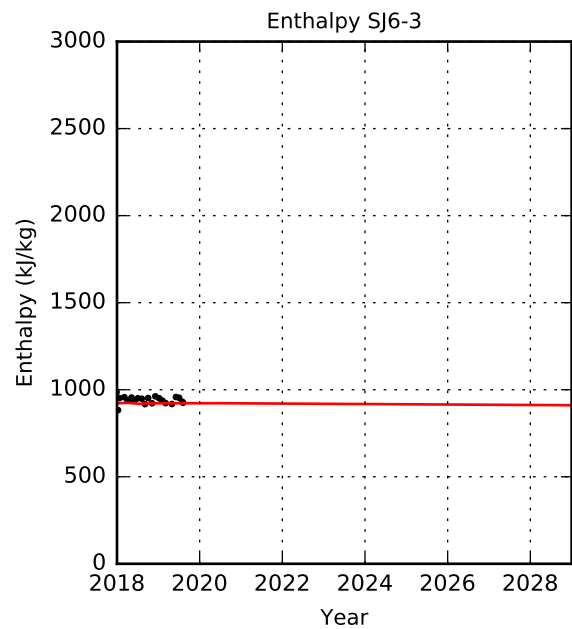
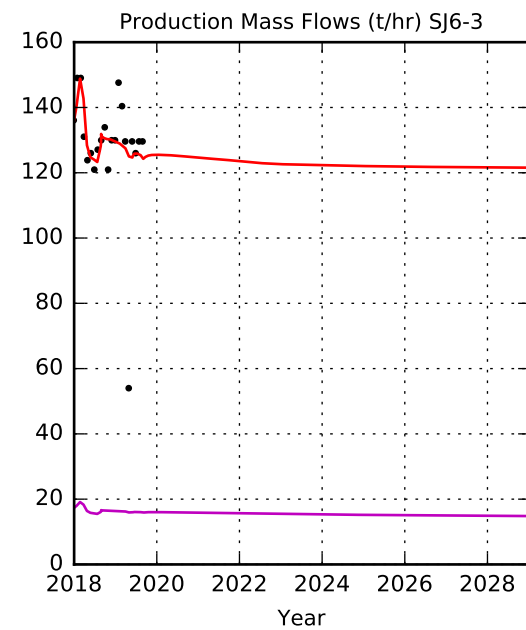
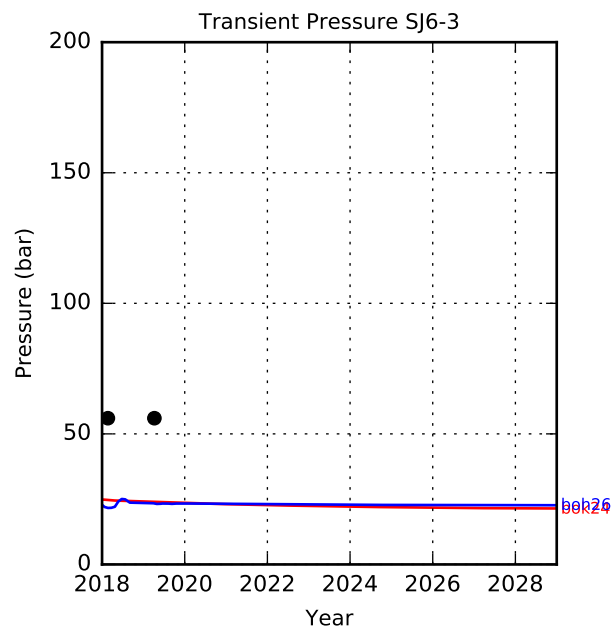
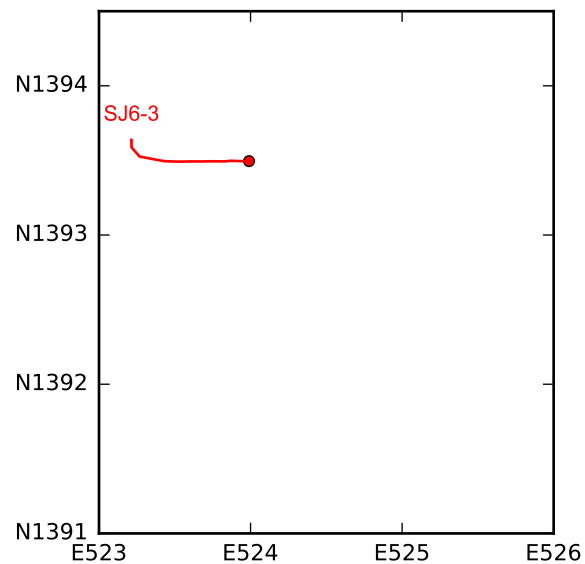


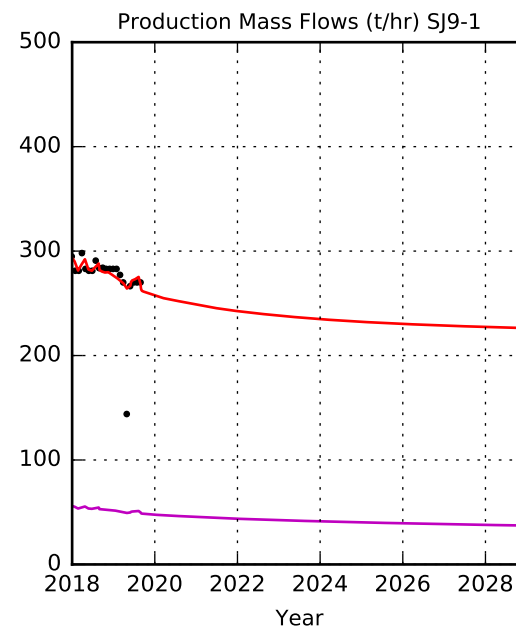
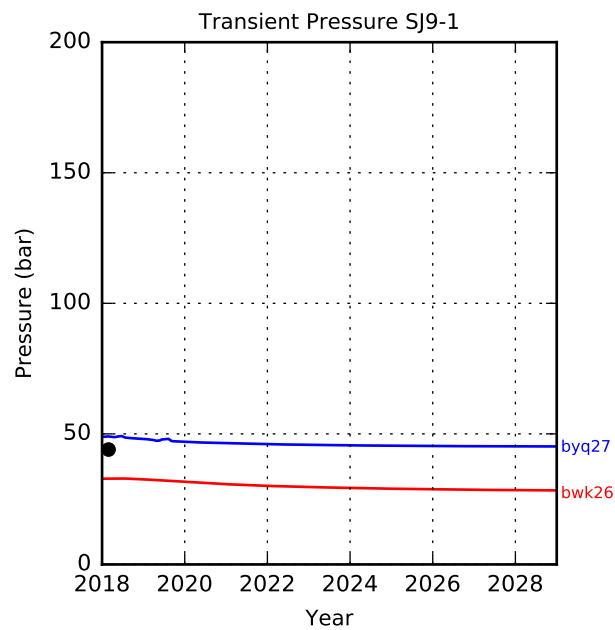
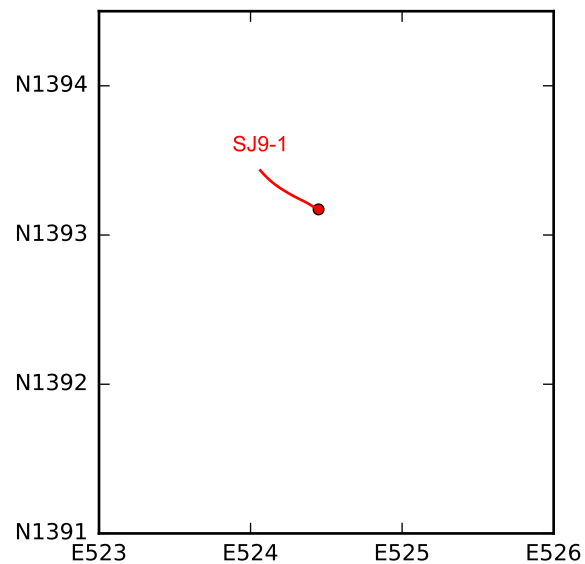


Feedzone Elevations
-700.0 masl -1500.0 masl

— Total Mass Flow — Steam Flow

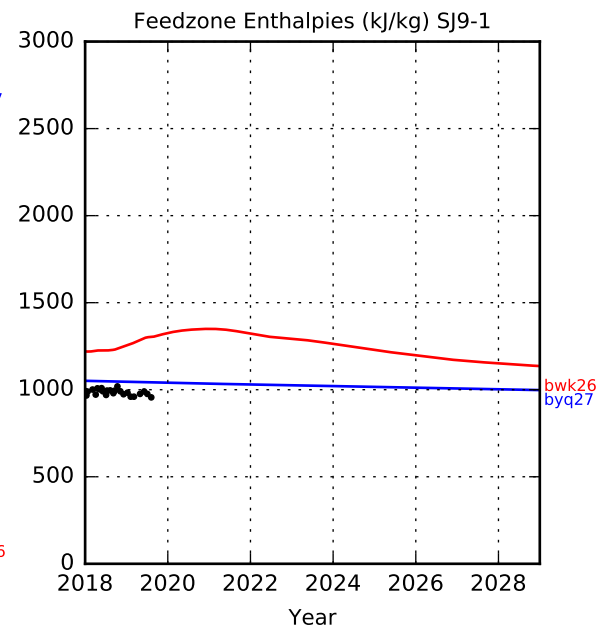
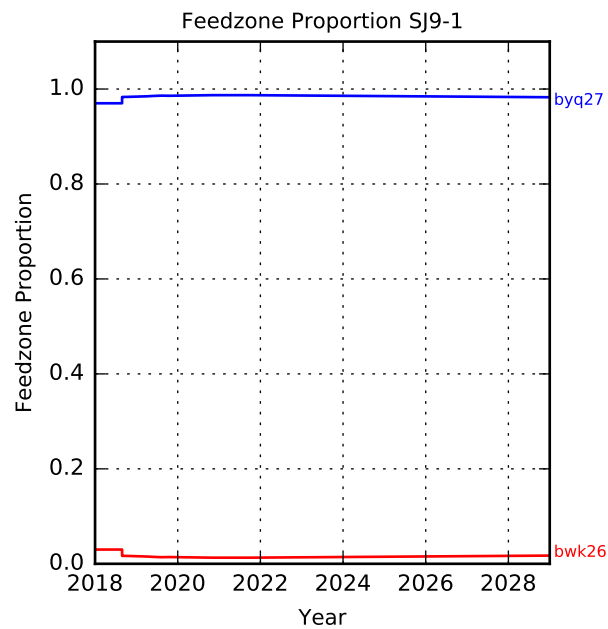
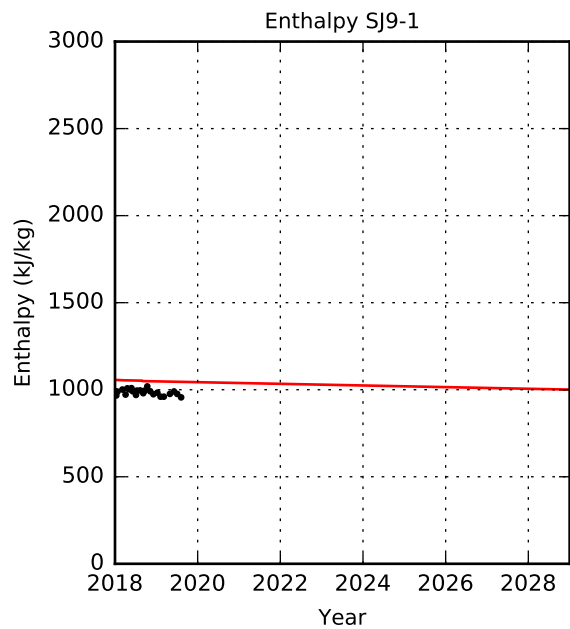


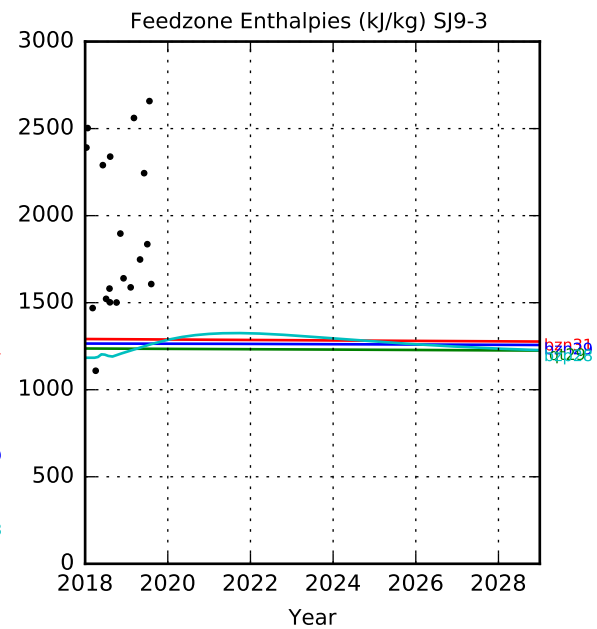
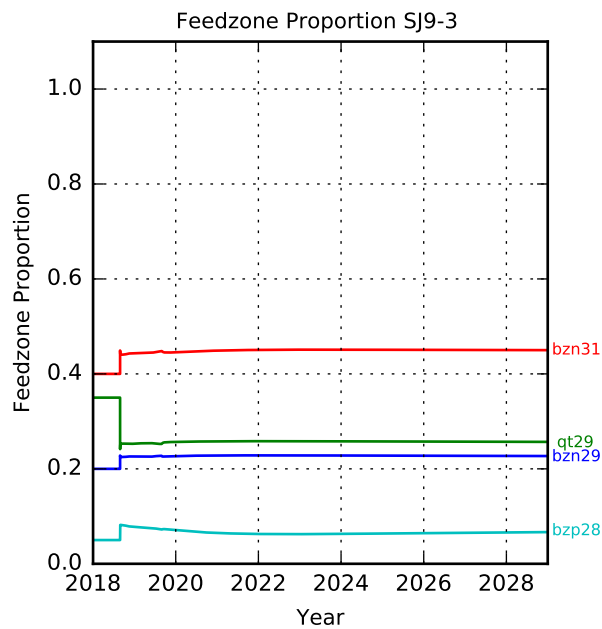
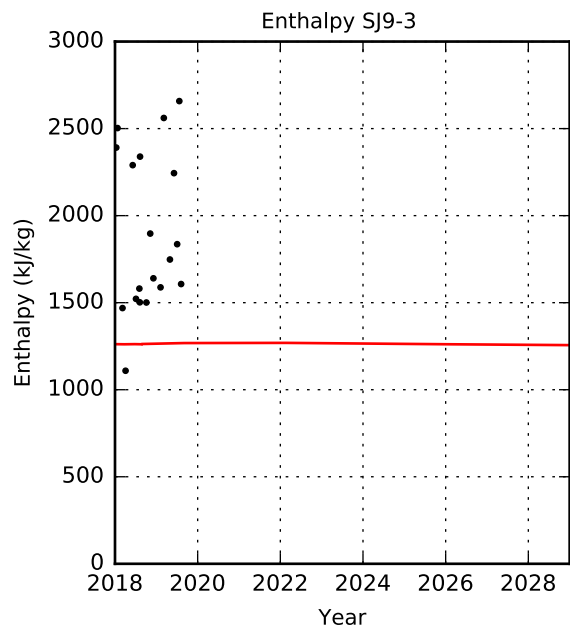
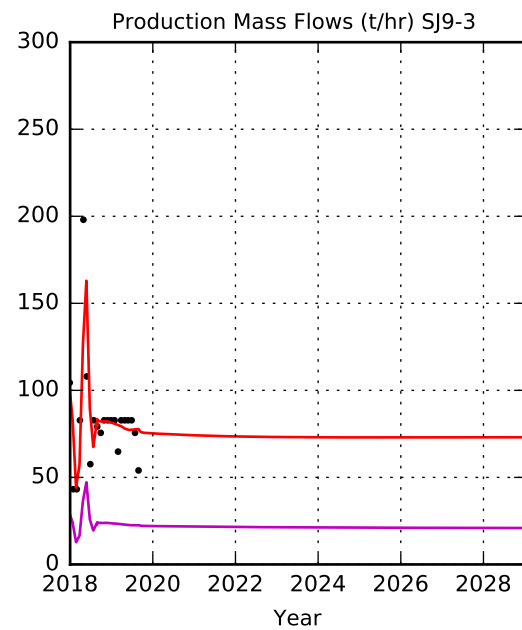
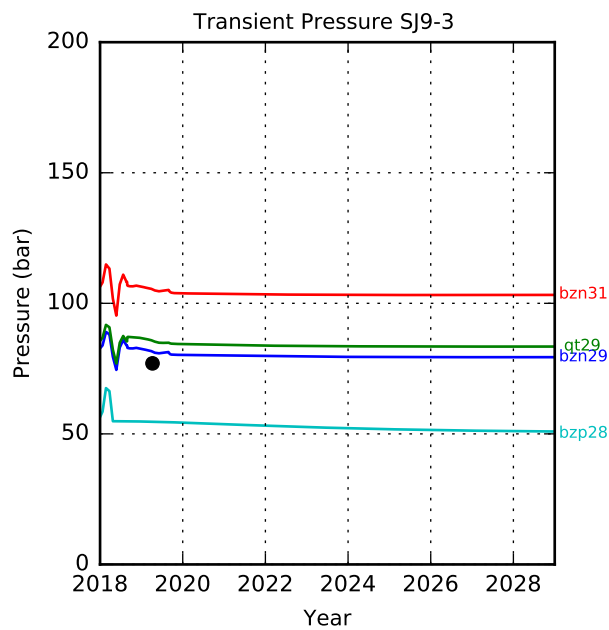
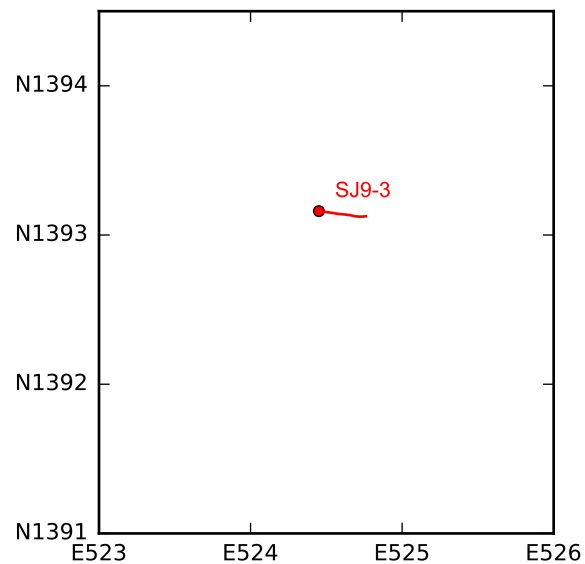


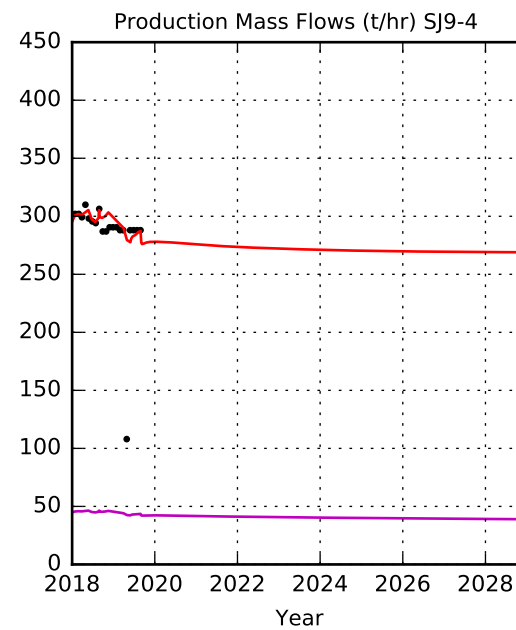
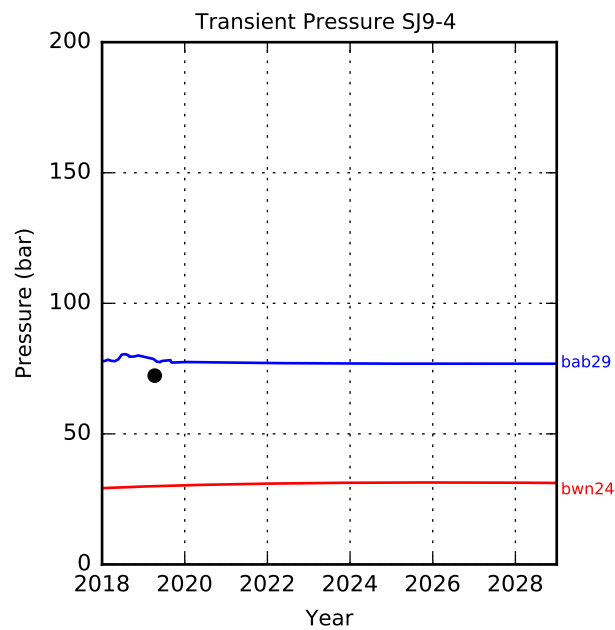
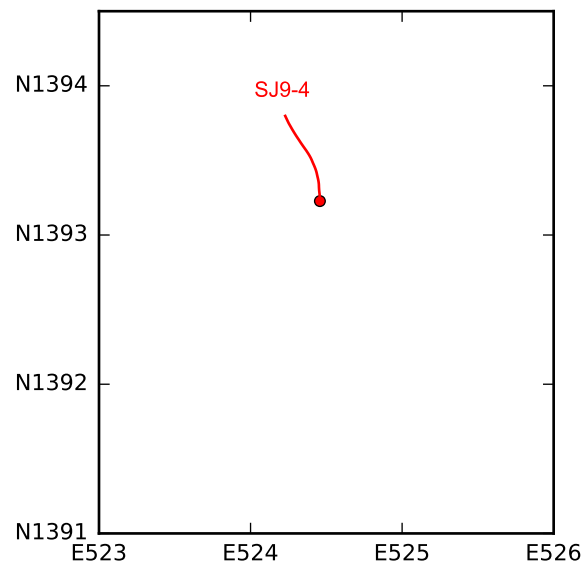


Feedzone Elevations

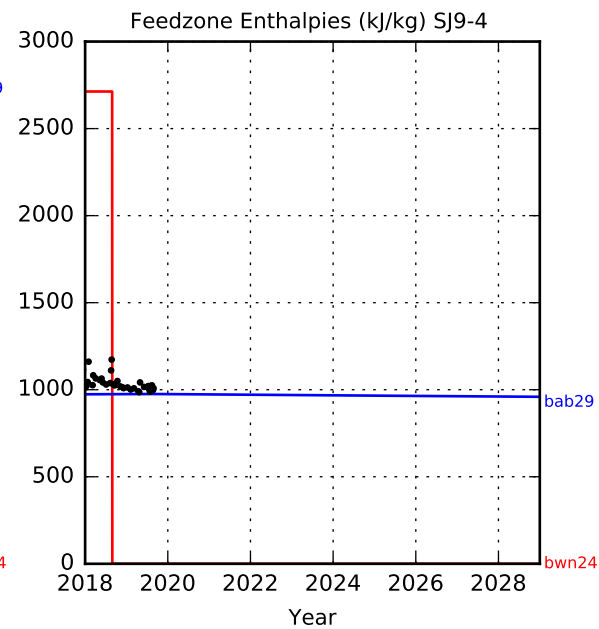
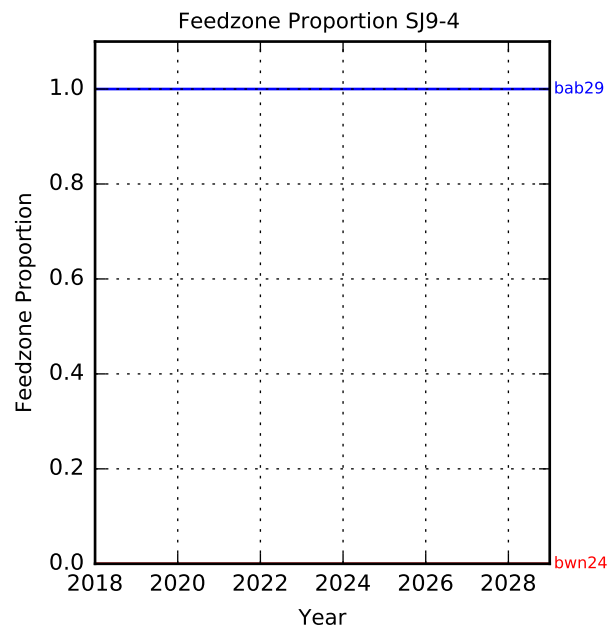
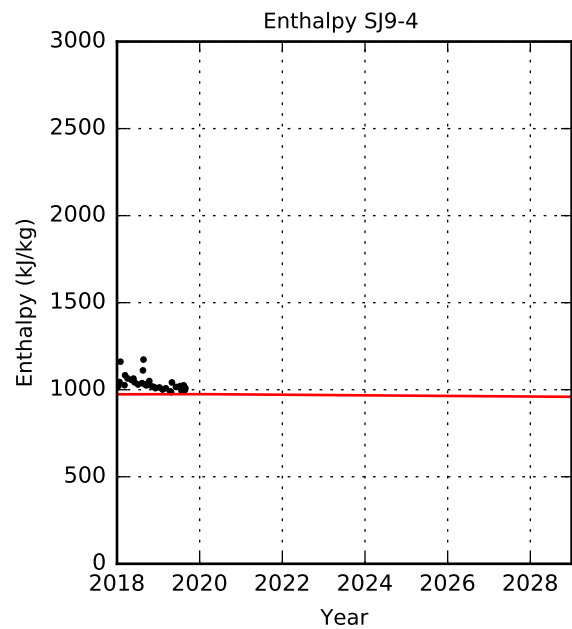
-525.0 masl -700.0 masl

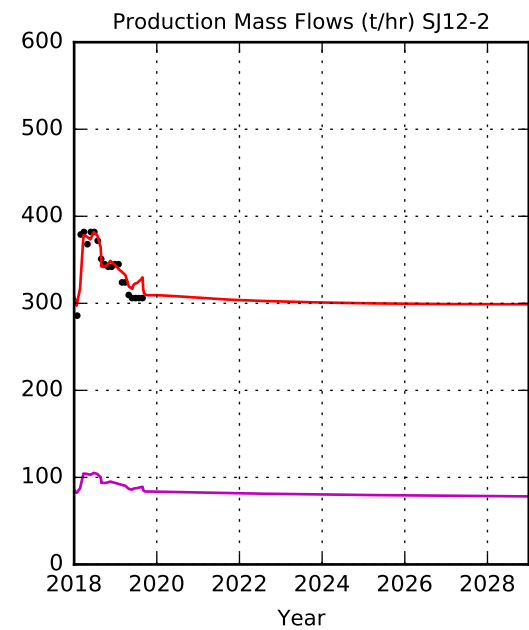
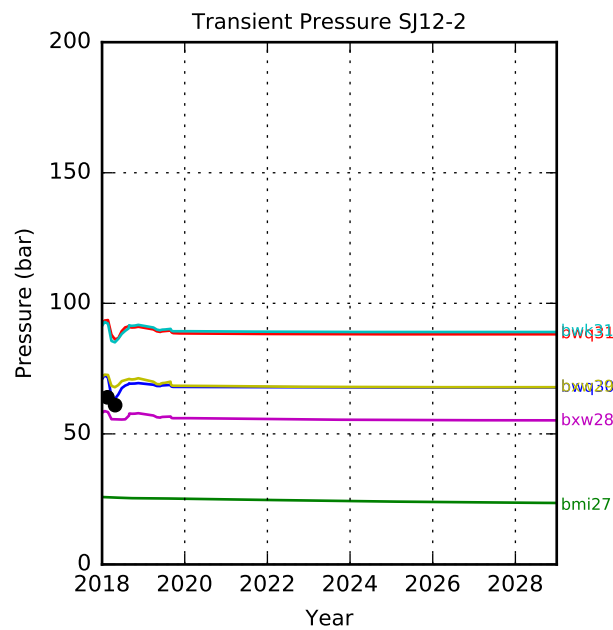
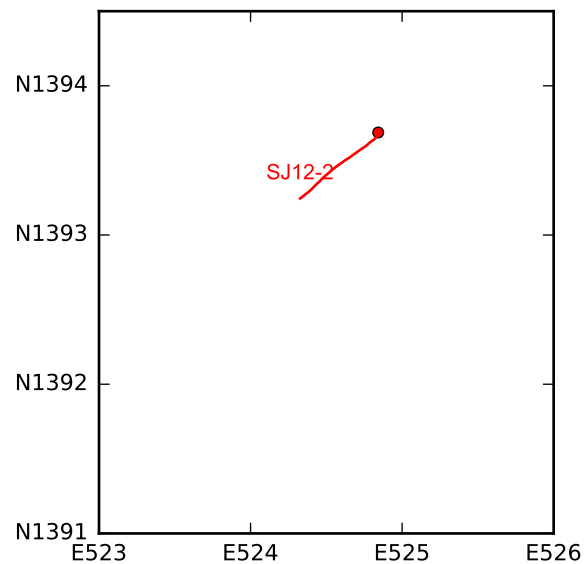






Feedzone Elevations
-250.0 masl -1100.0 masl

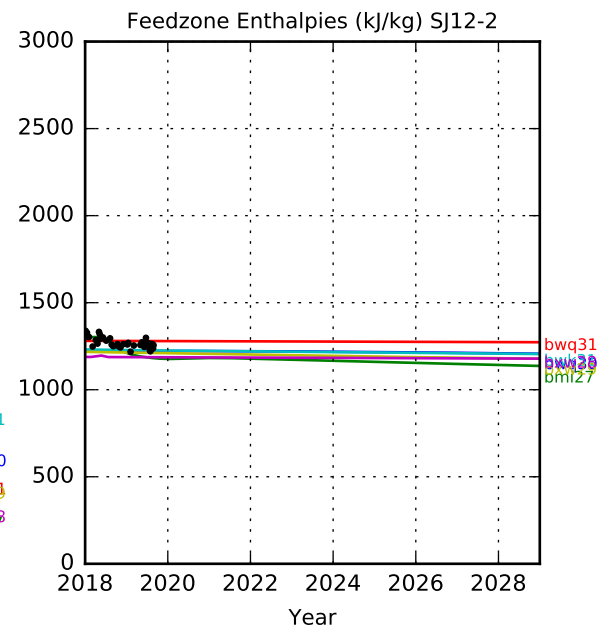
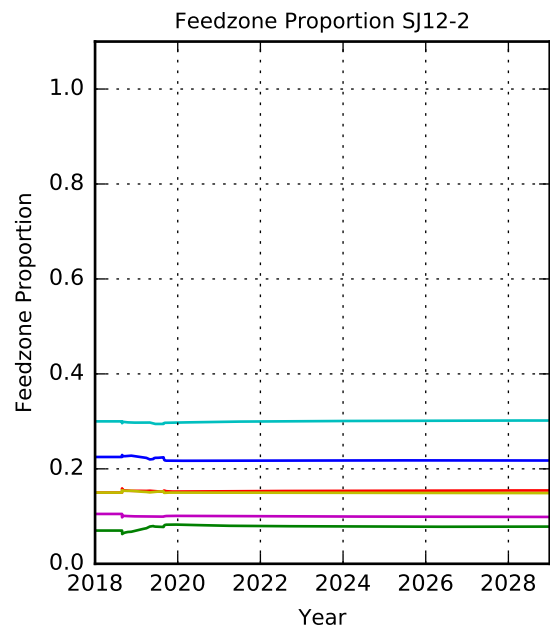
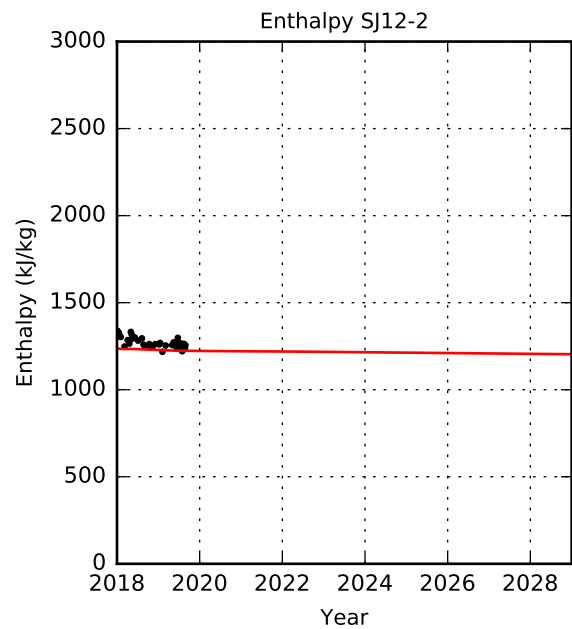


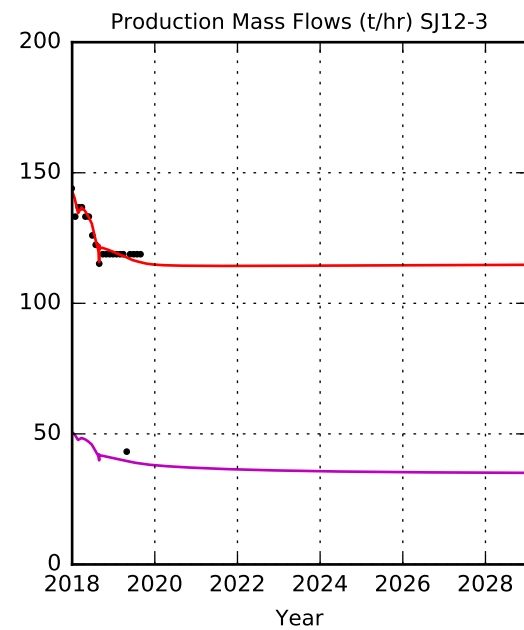
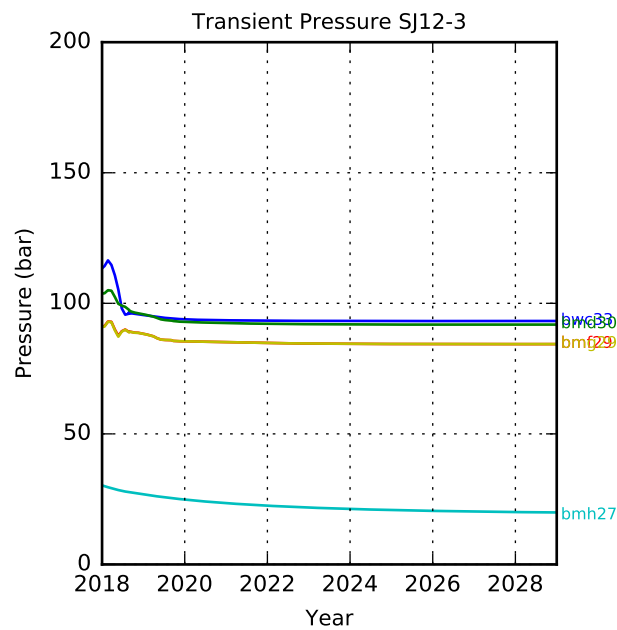
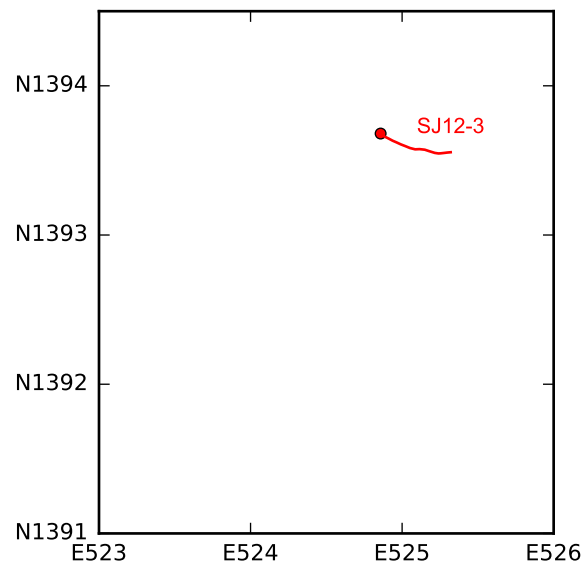


Feedzone Elevations

-1500.0 masl	-1300.0 masl	-700.0 masl
-1500.0 masl	-1100.0 masl	-900.0 masl

— Total Mass Flow — Steam Flow

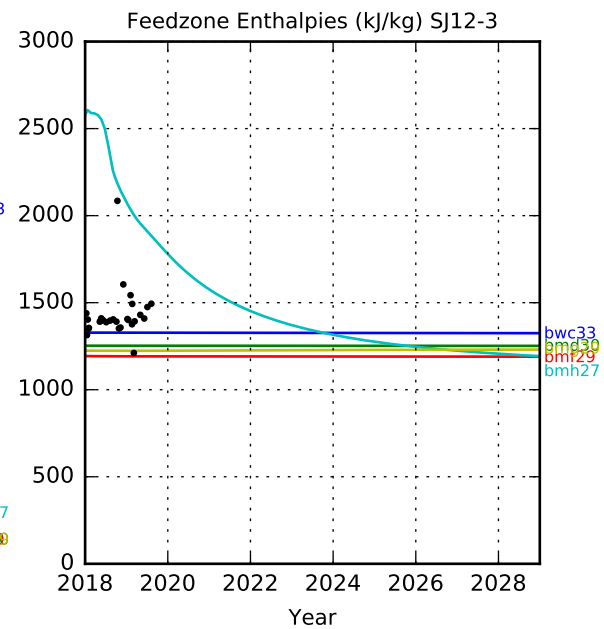
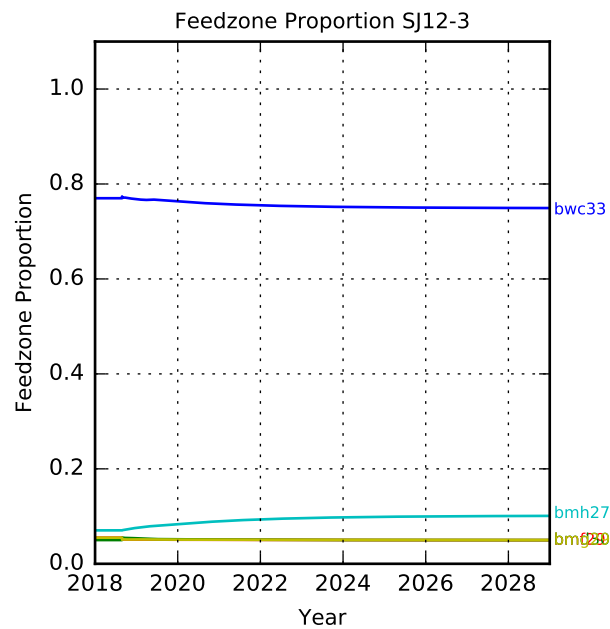
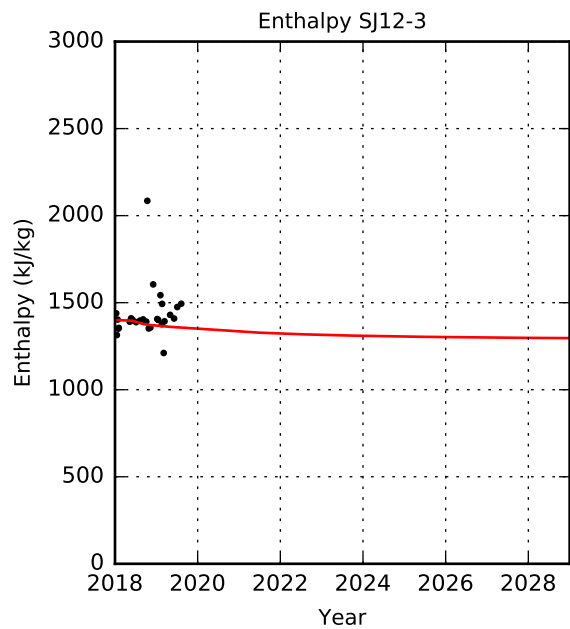


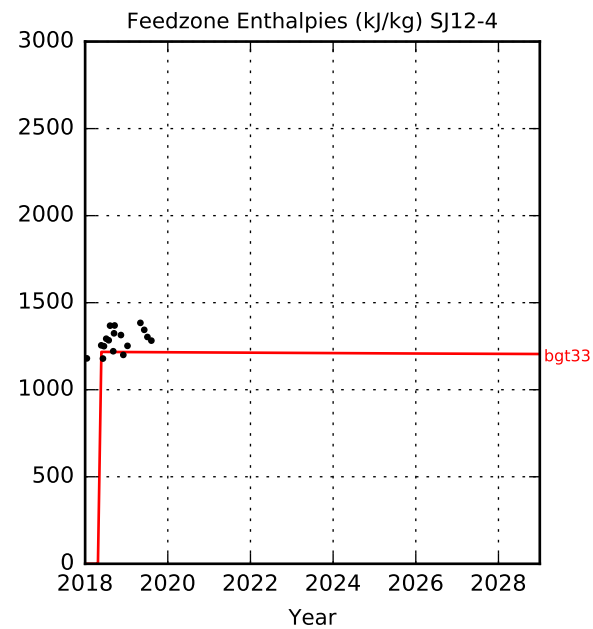
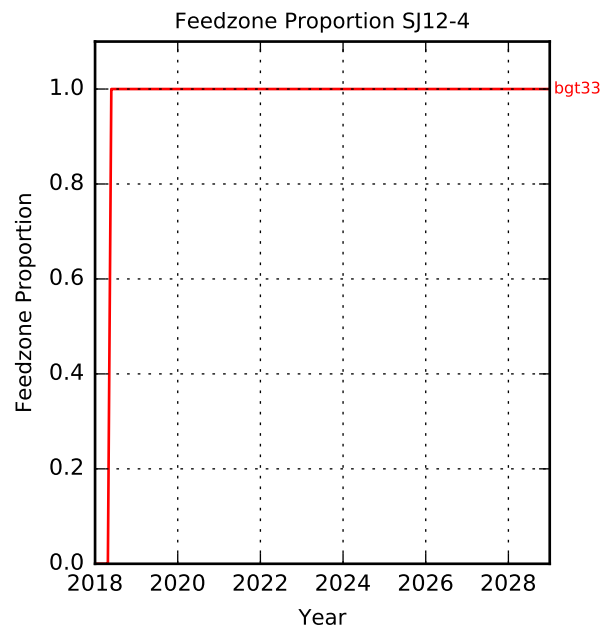
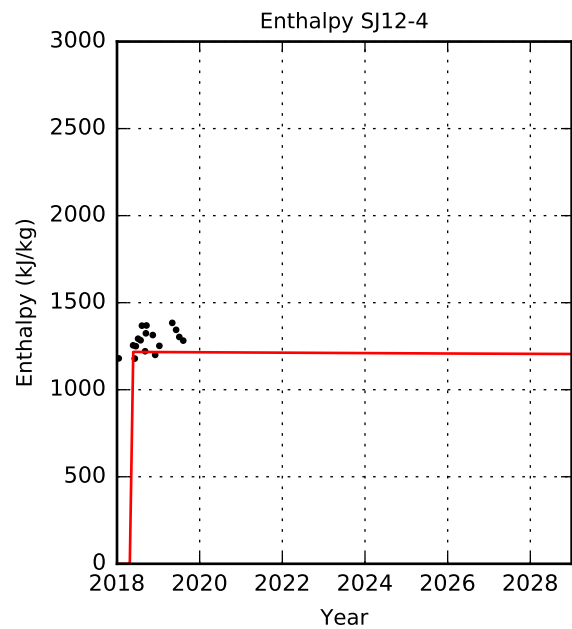
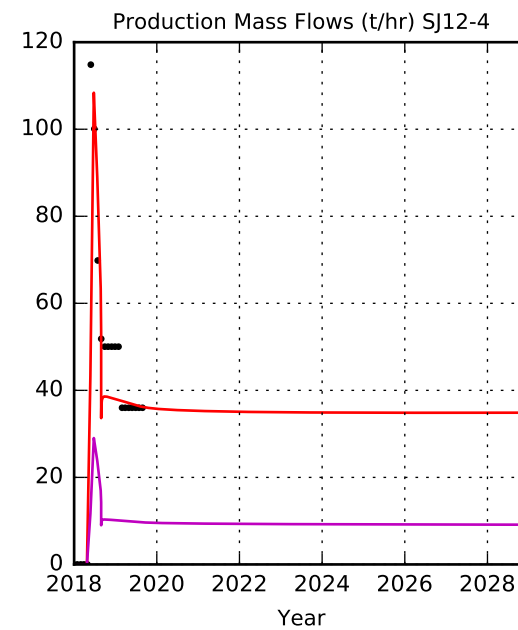
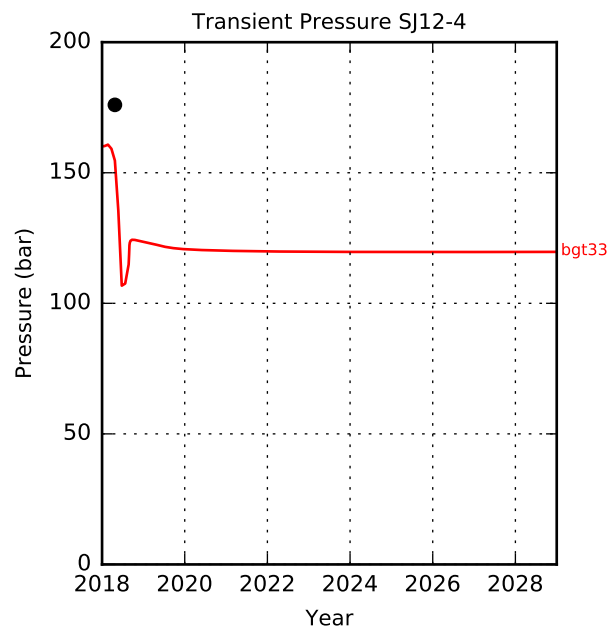
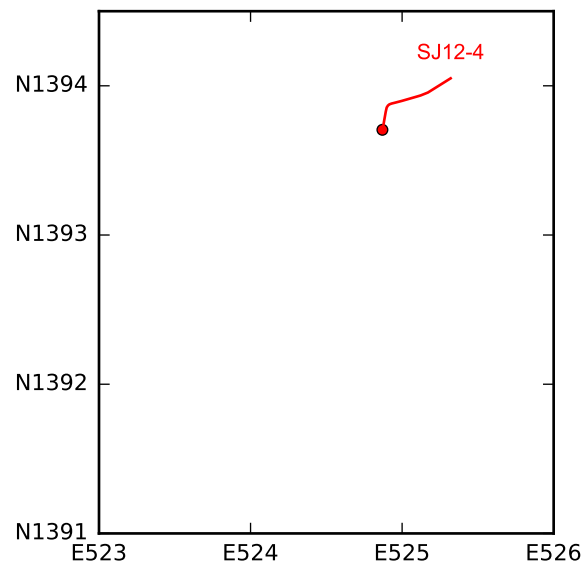


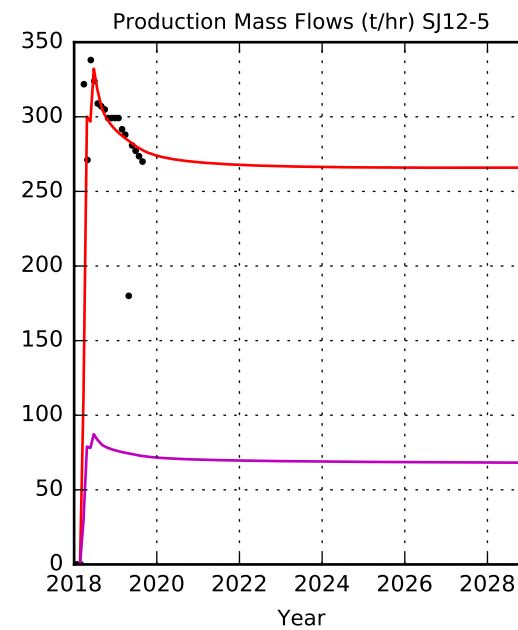
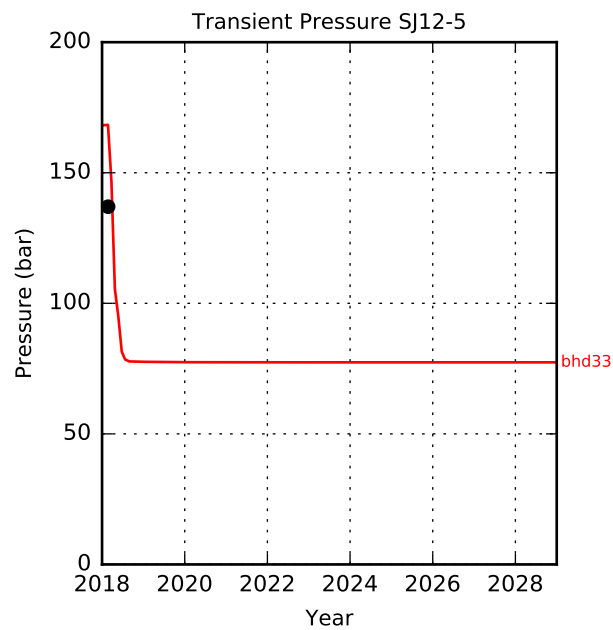
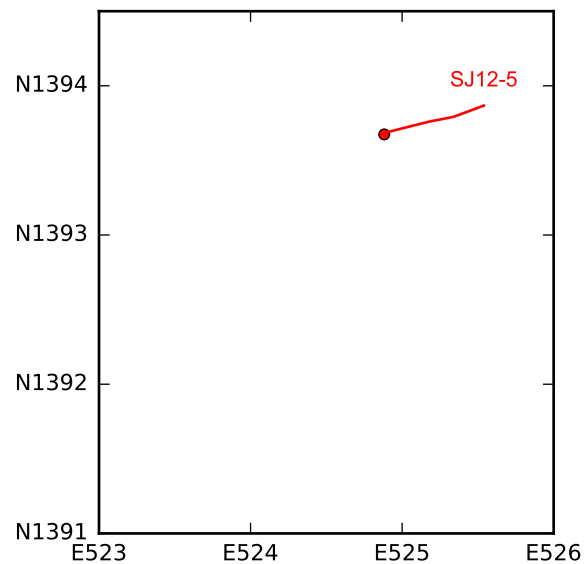
Feedzone Elevations

- 1100.0 masl
- 2000.0 masl
- 1300.0 masl
- 700.0 masl
- 1100.0 masl

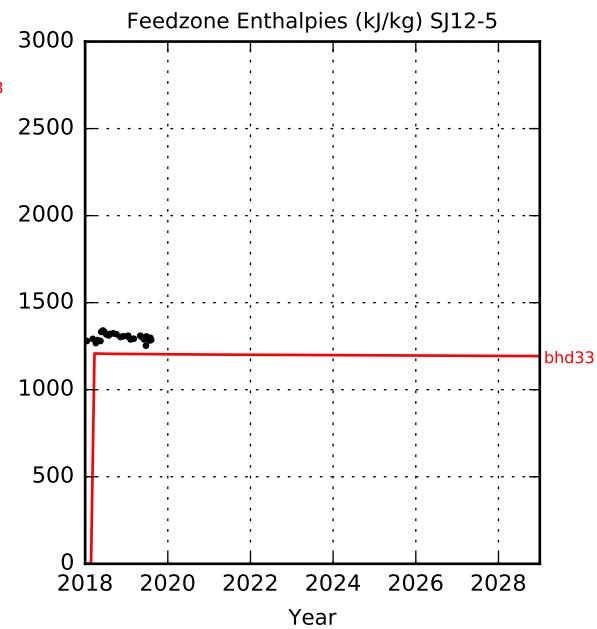
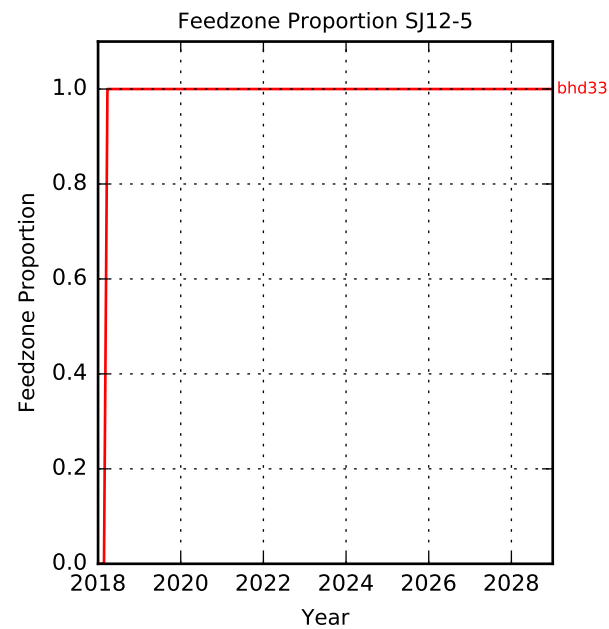
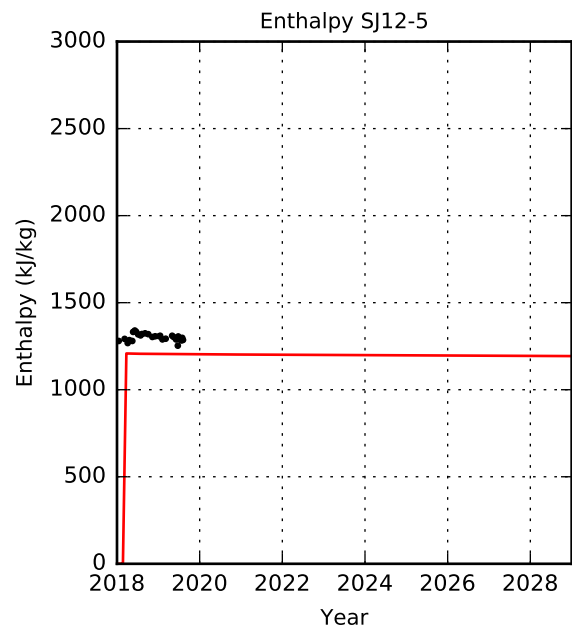
— Total Mass Flow — Steam Flow

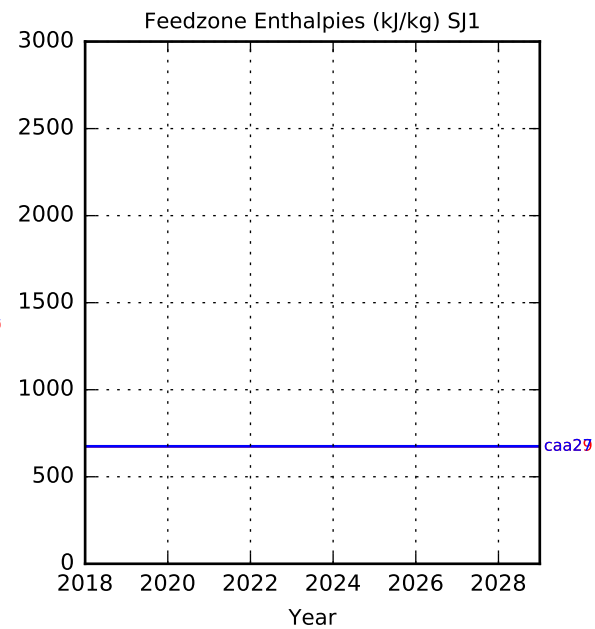
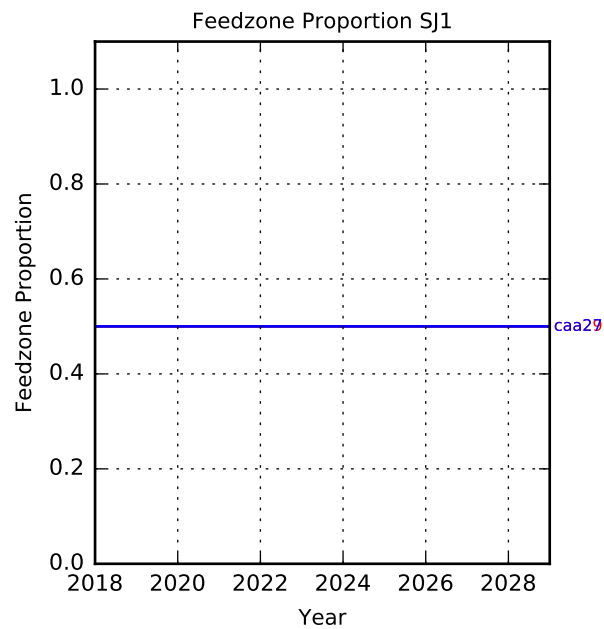
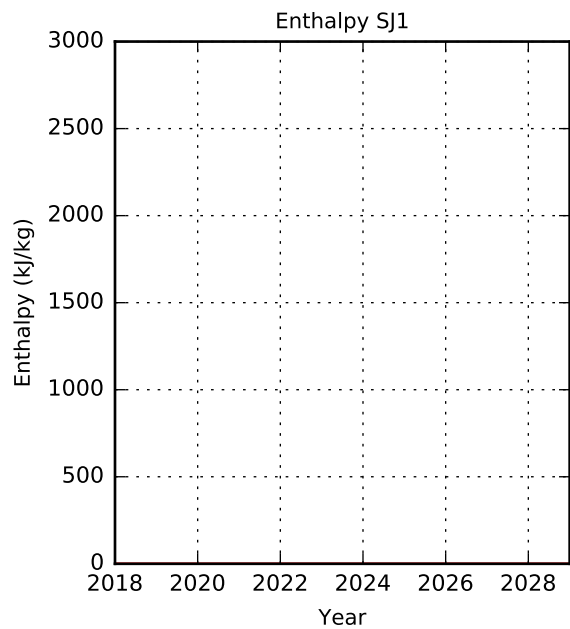
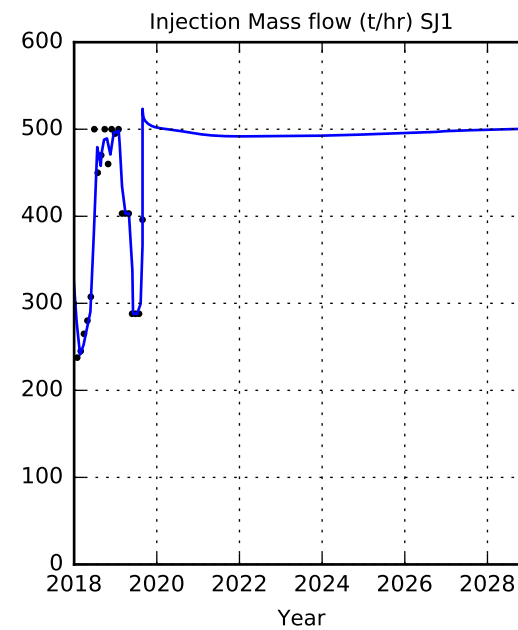
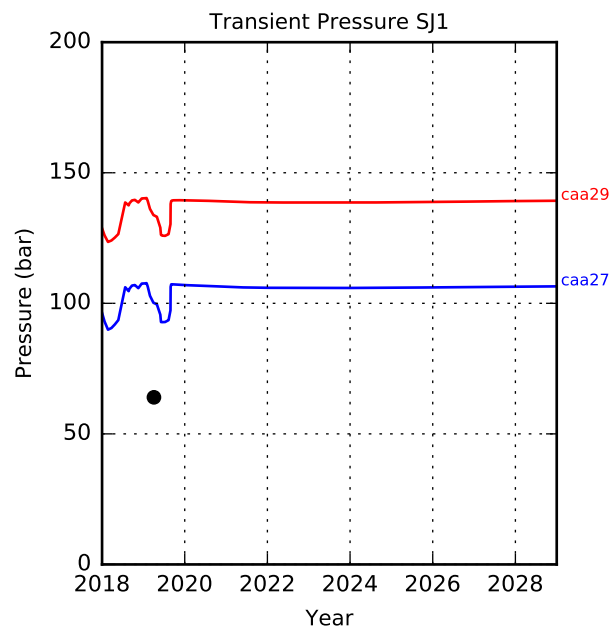
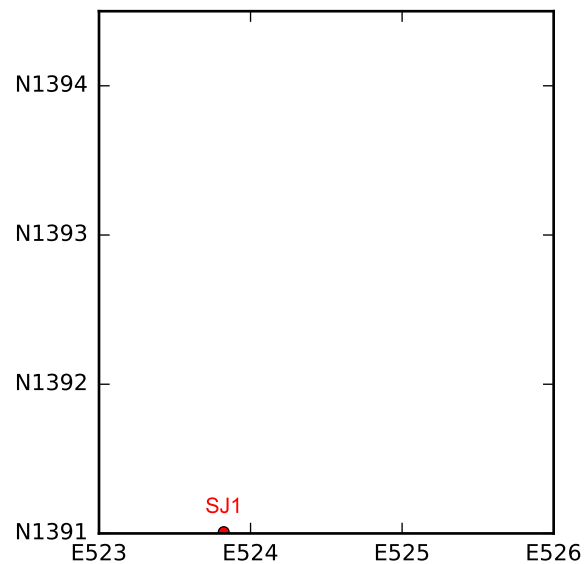


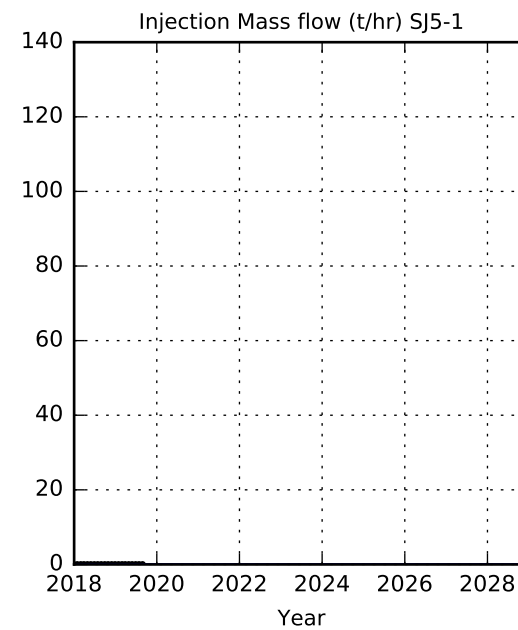
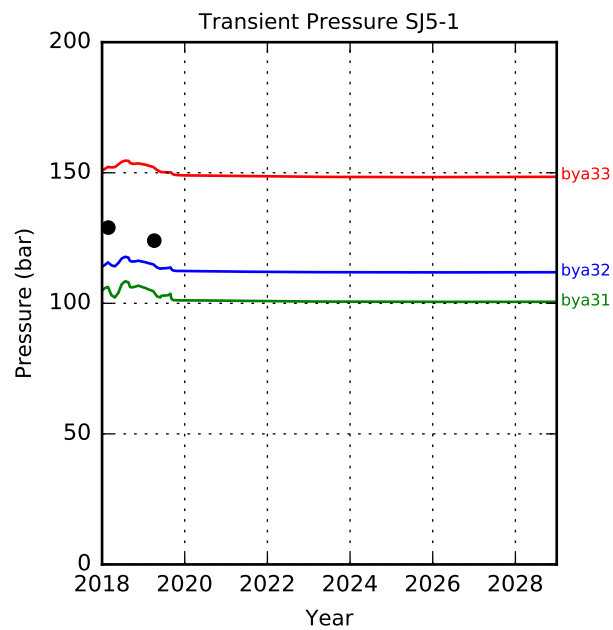
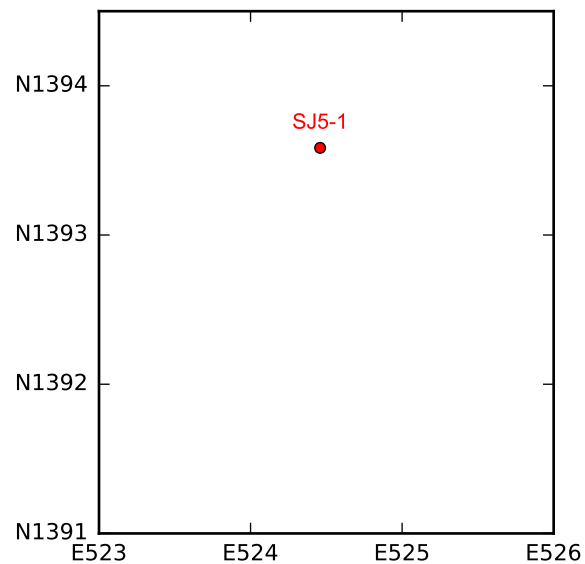




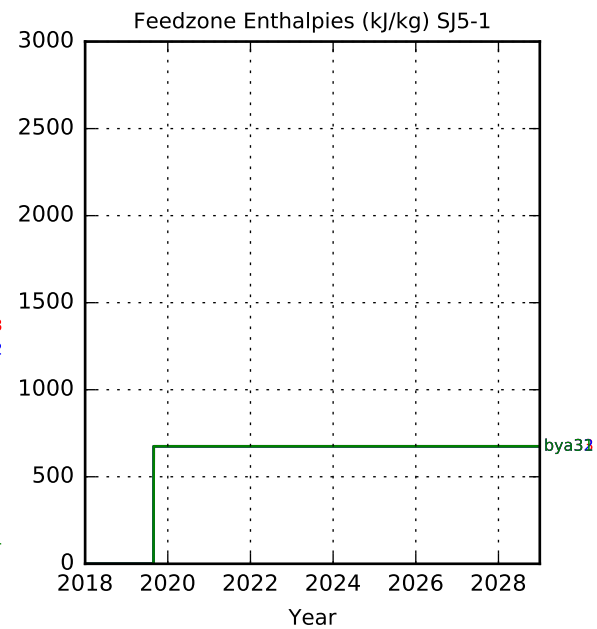
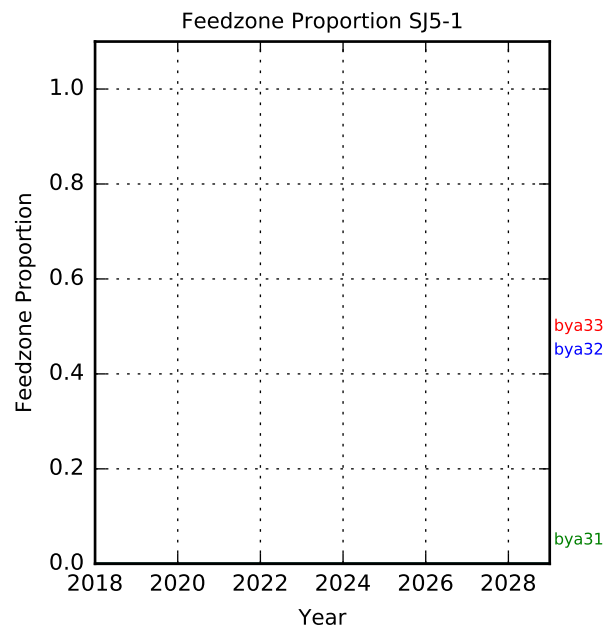
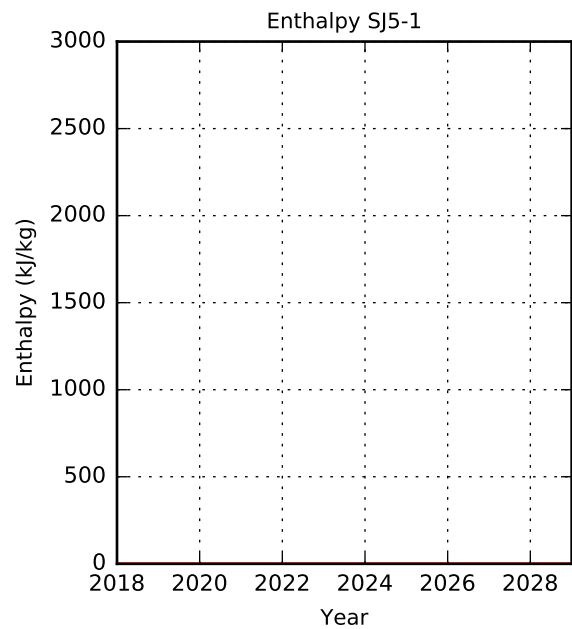
— Total Mass Flow — Steam Flow

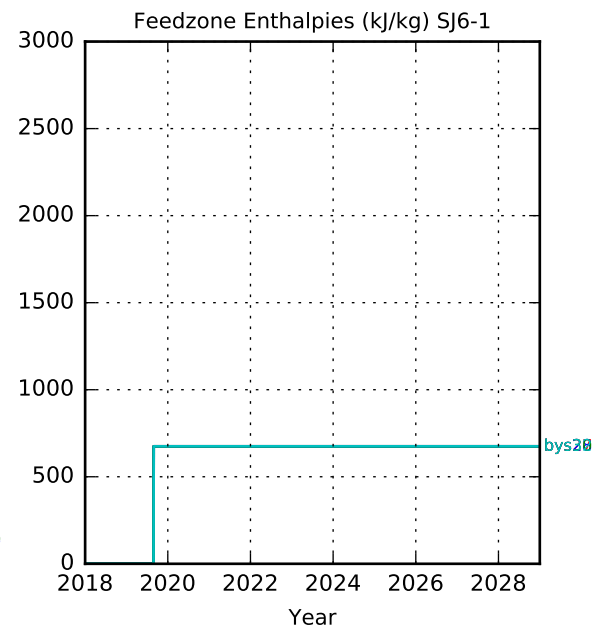
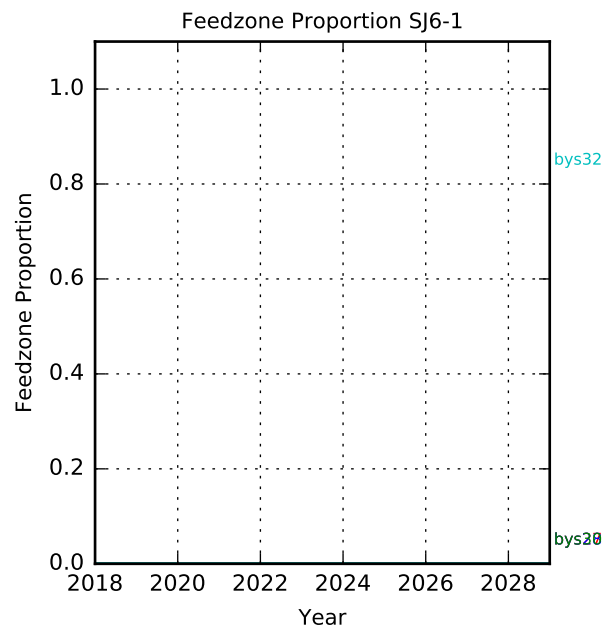
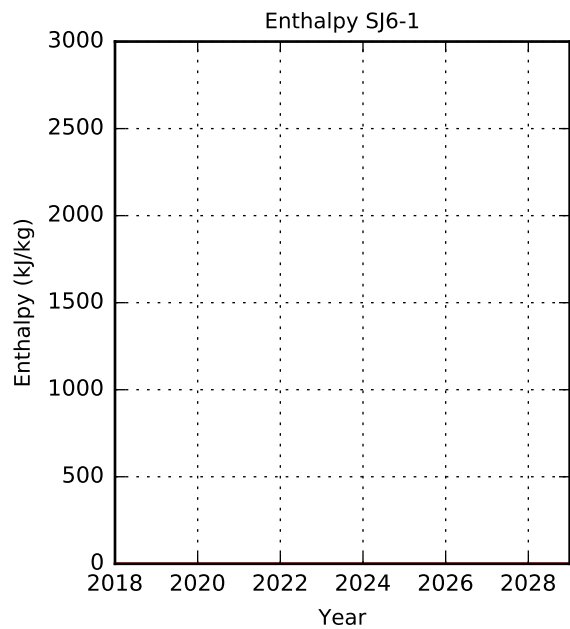
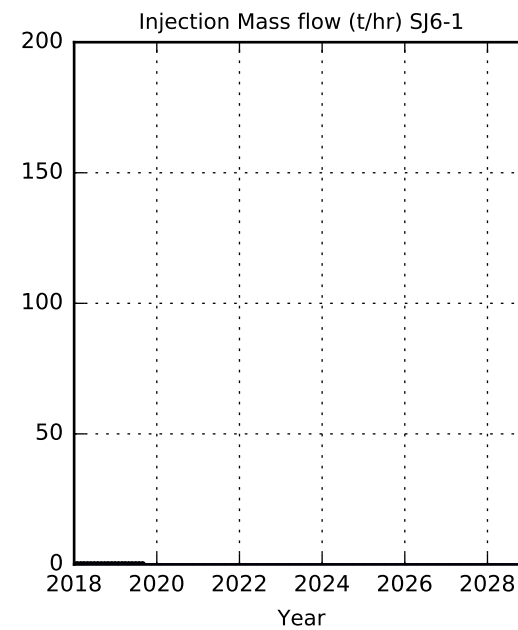
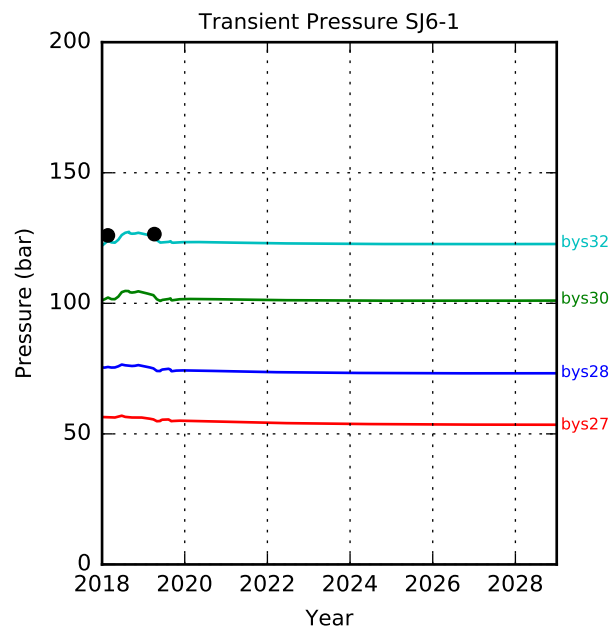
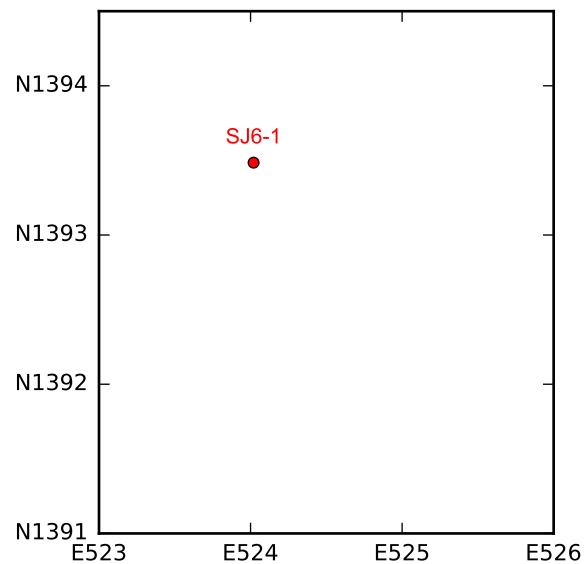


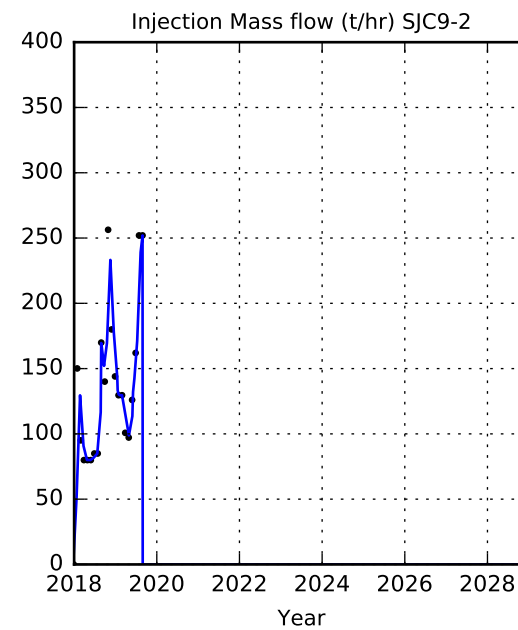
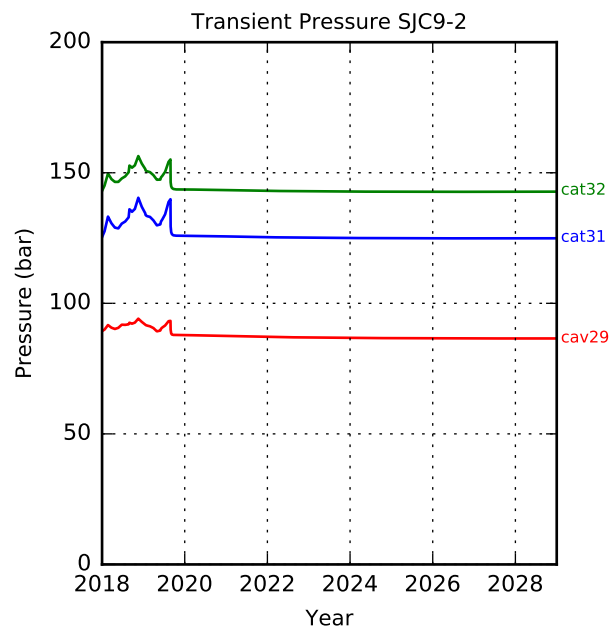
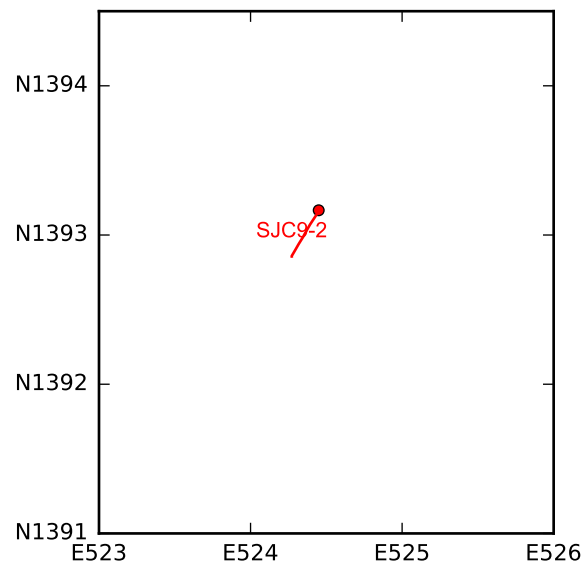




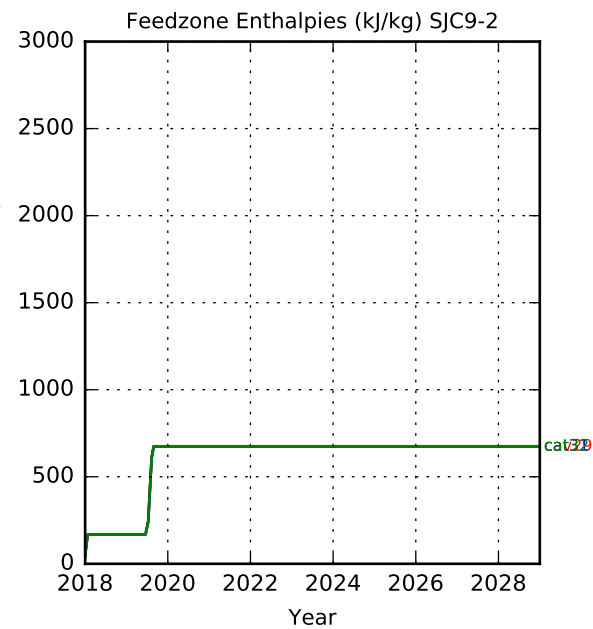
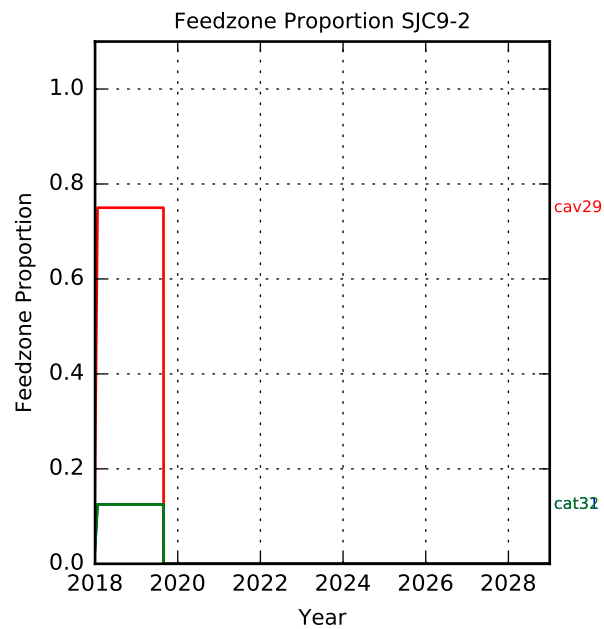
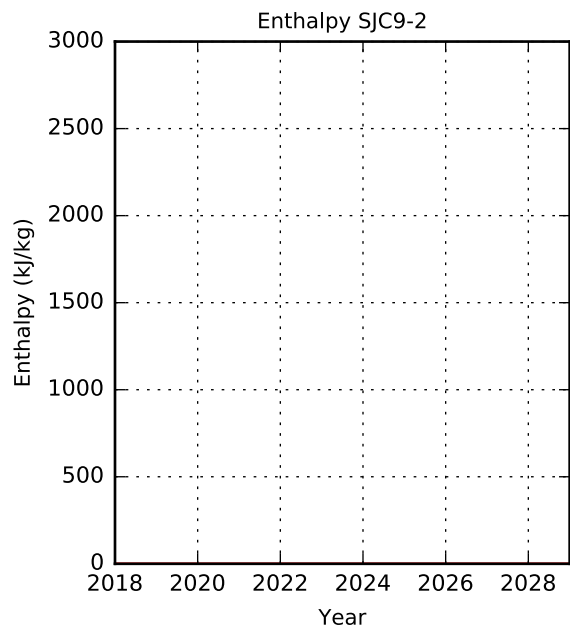
Feedzone Elevations
-2000.0 masl -1700.0 masl -1500.0 masl

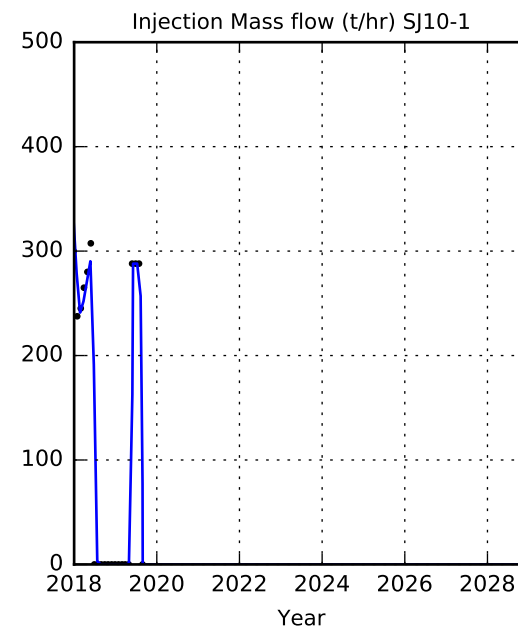
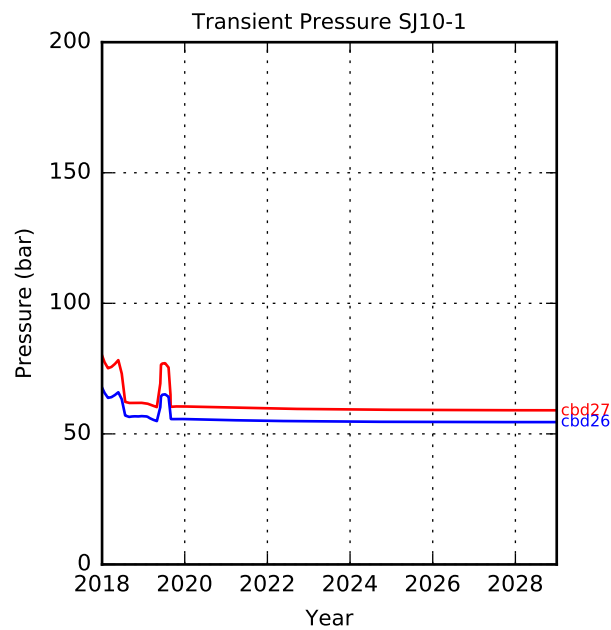
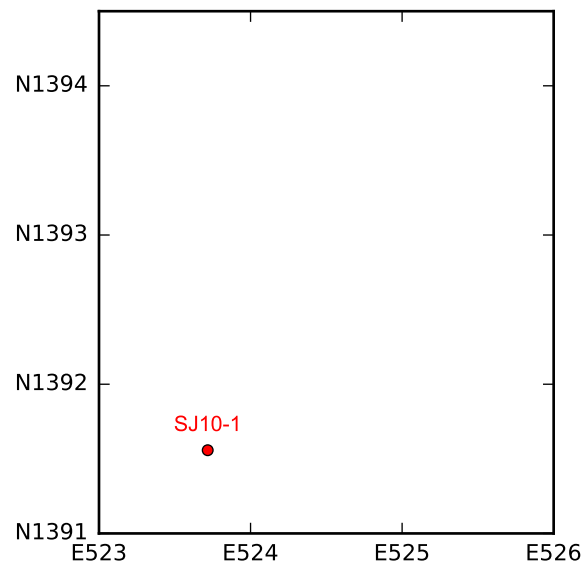




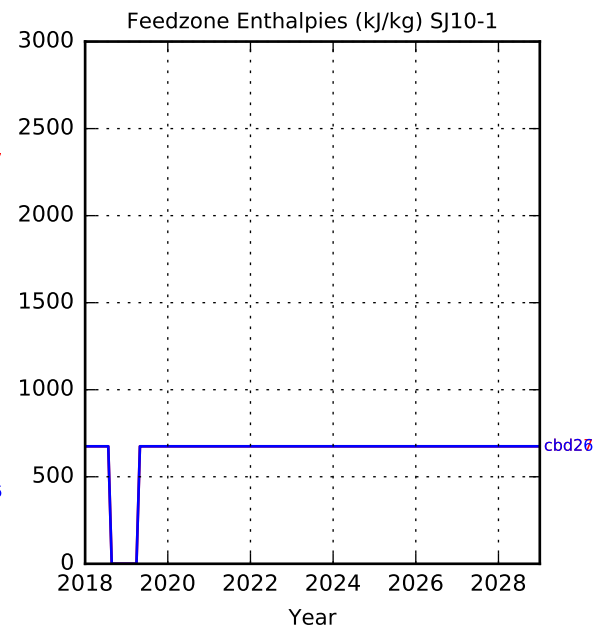
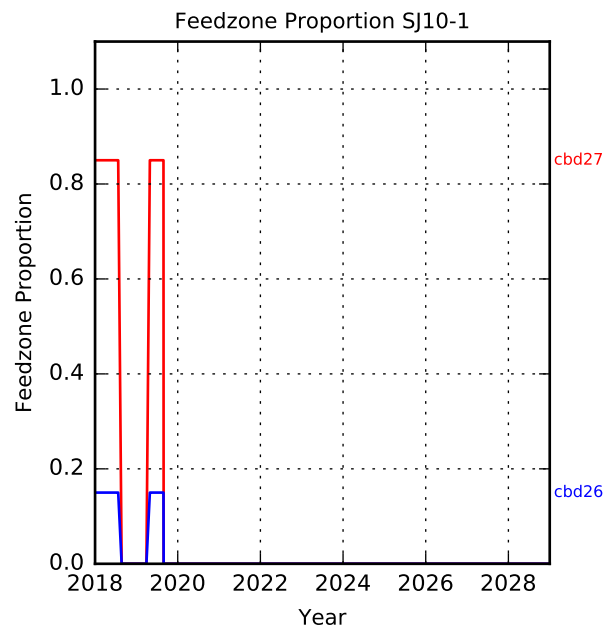
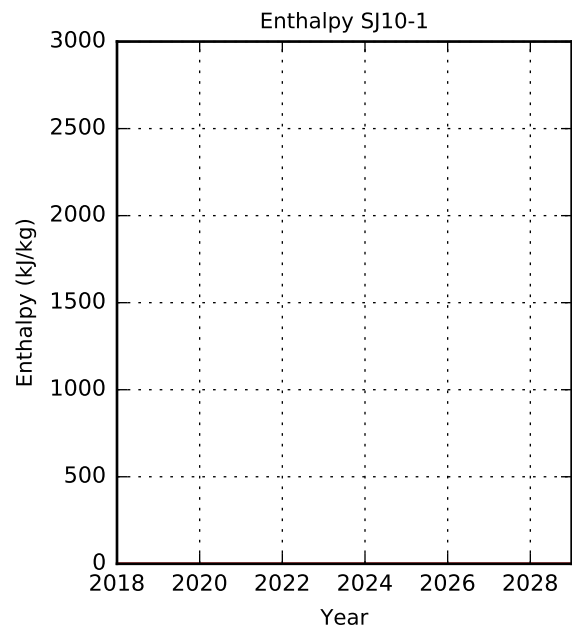


Feedzone Elevations
-1100.0 masl -1500.0 masl -1700.0 masl

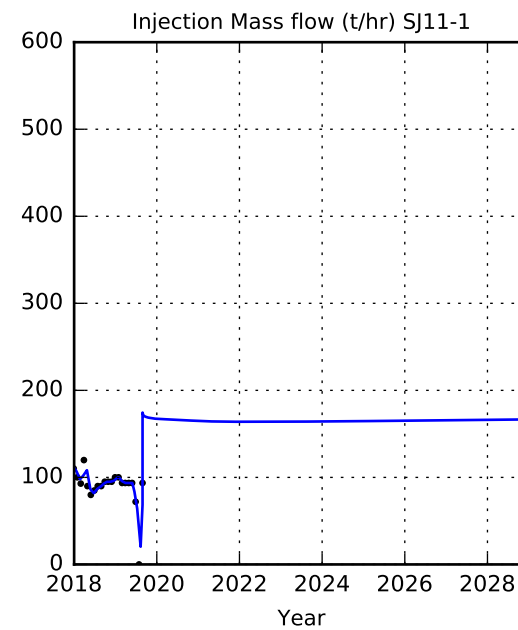
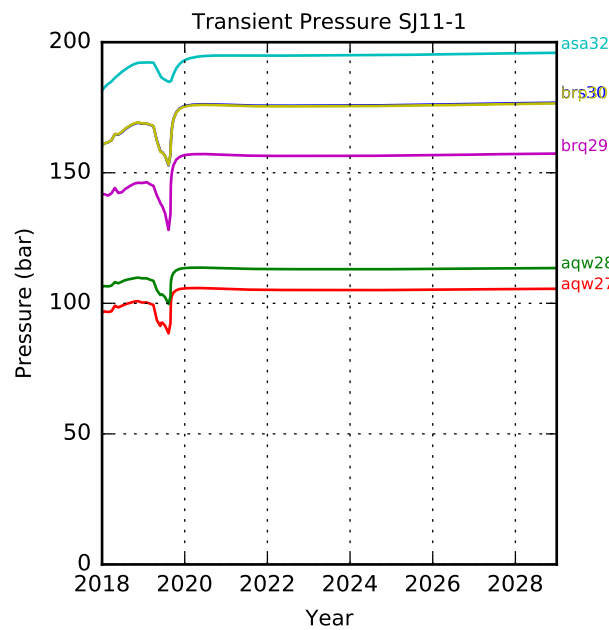
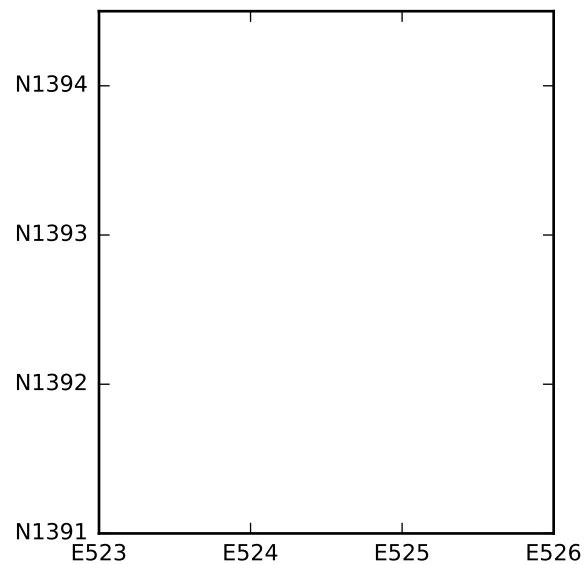




Feedzone Elevations
-700.0 masl -525.0 masl

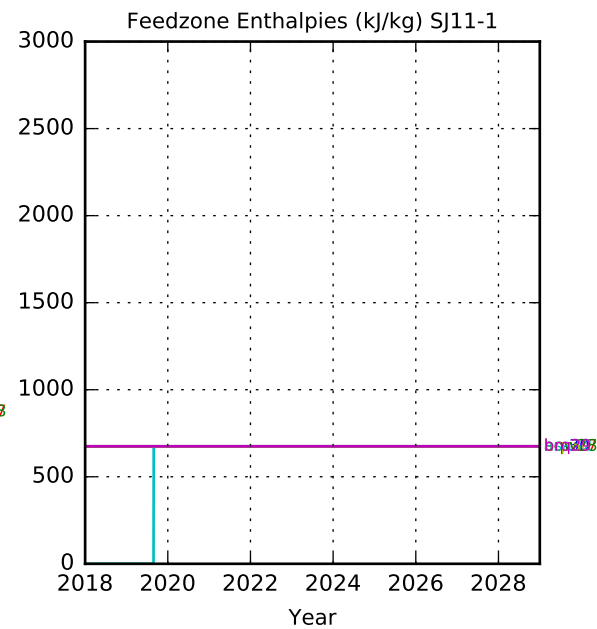
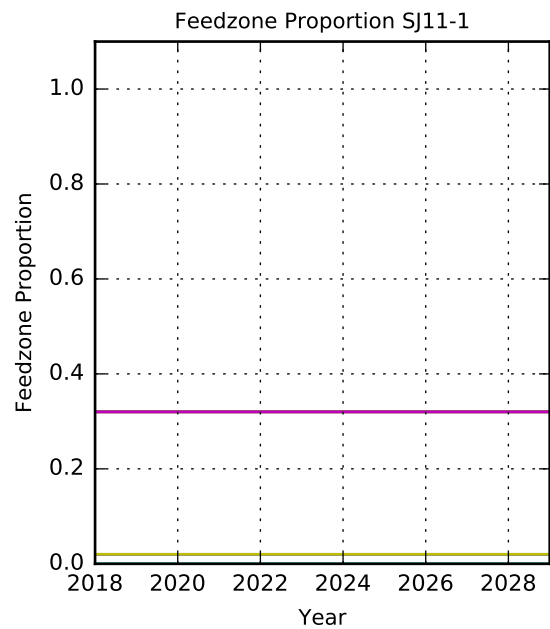
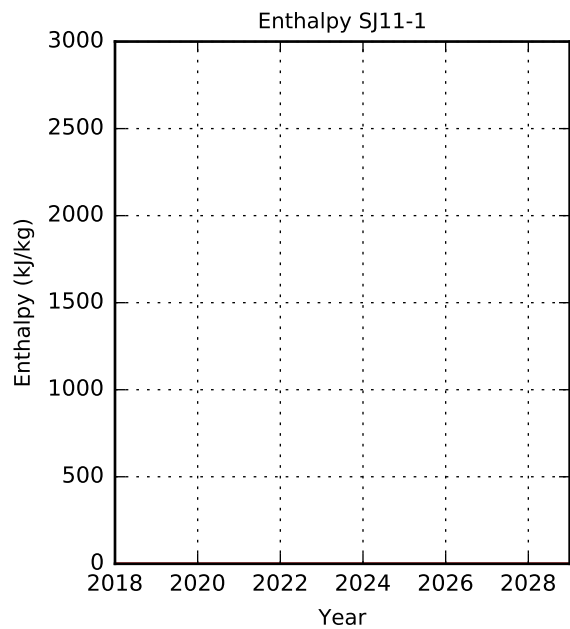


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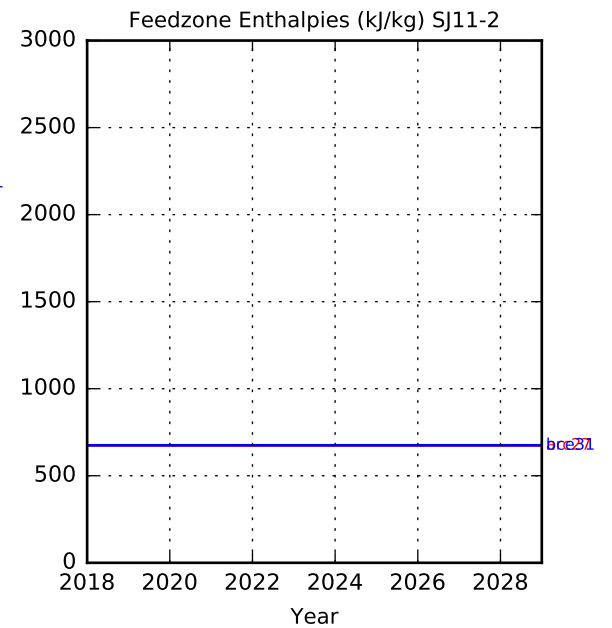
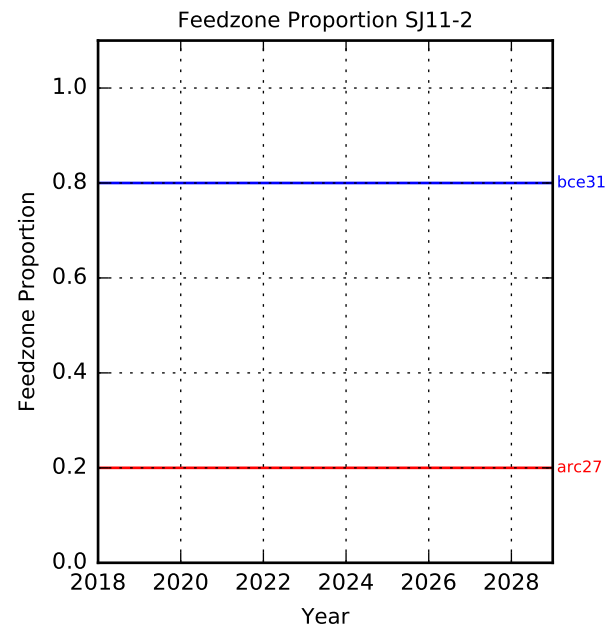
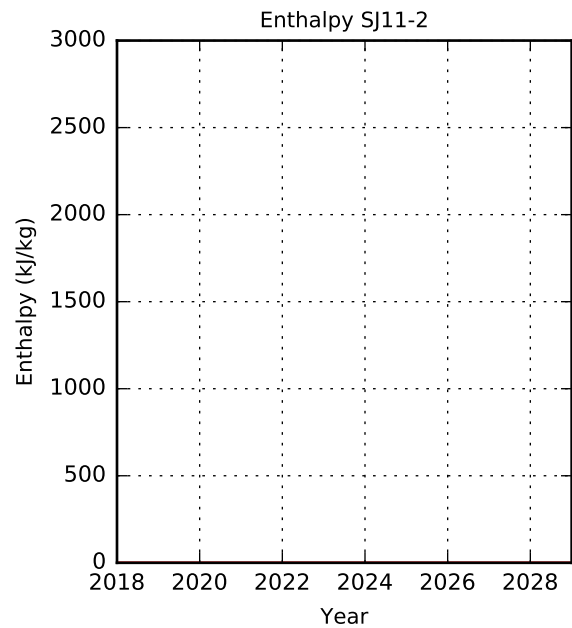
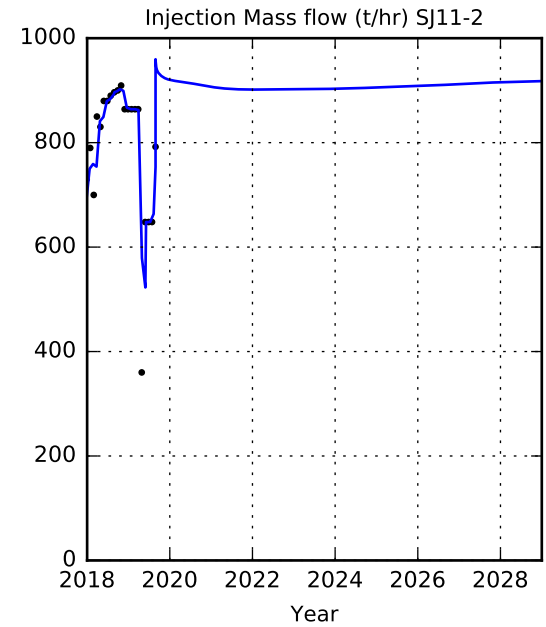
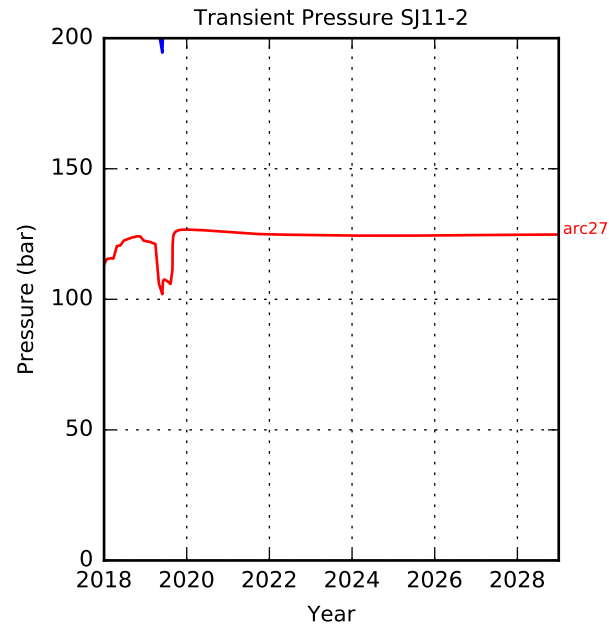
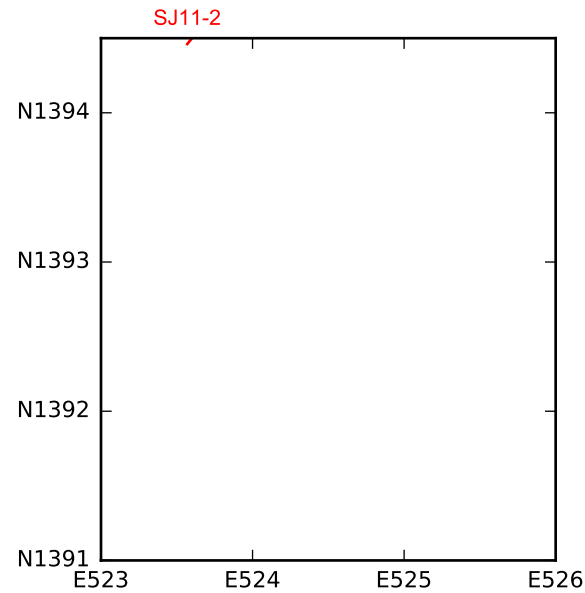


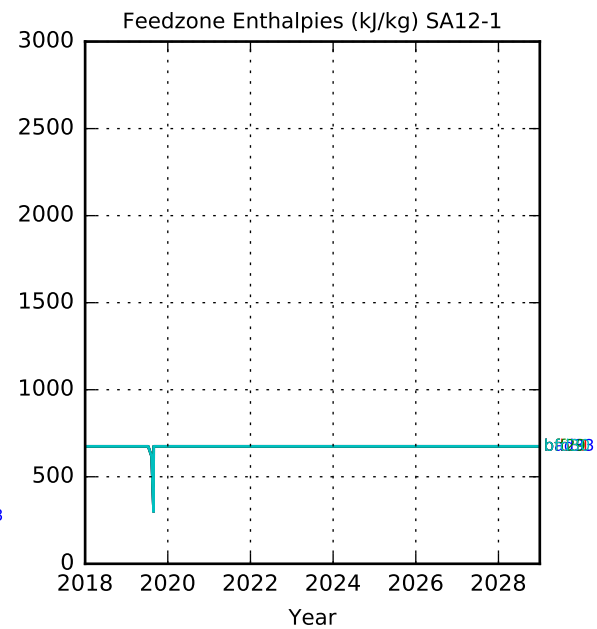
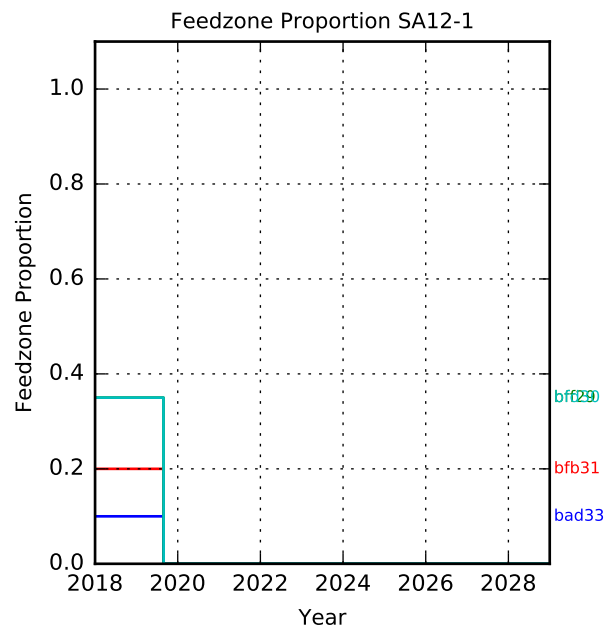
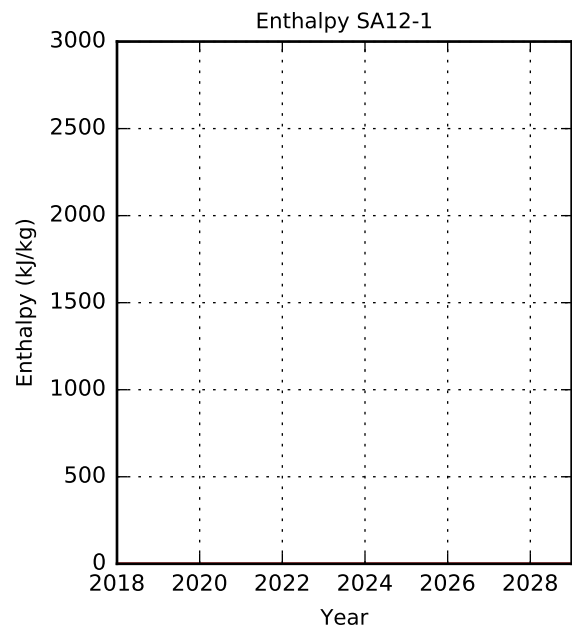
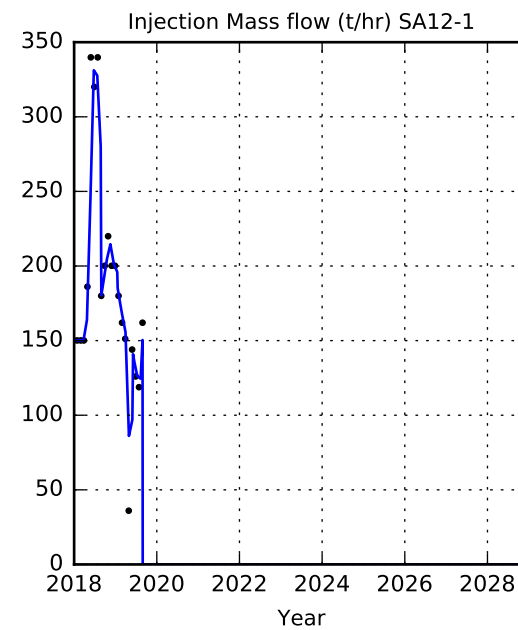
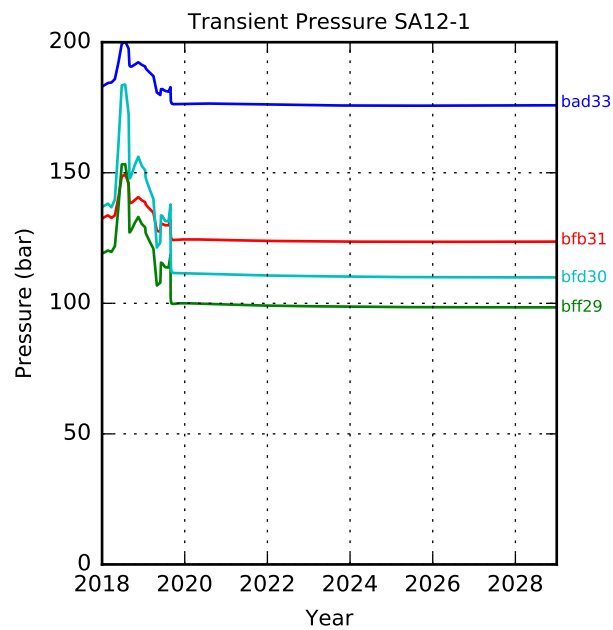
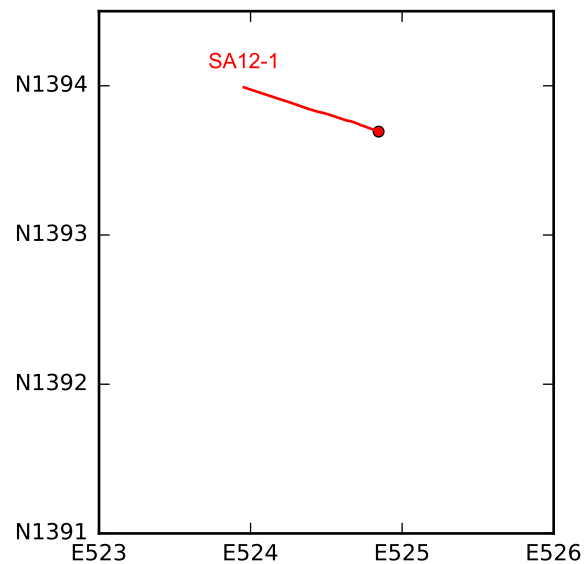
Feedzone Elevations

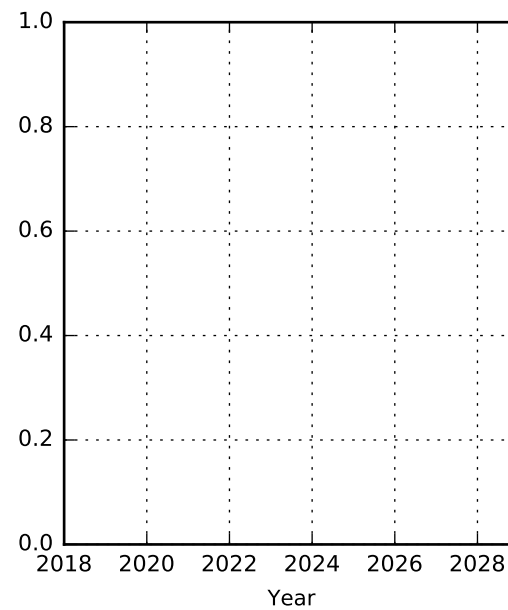
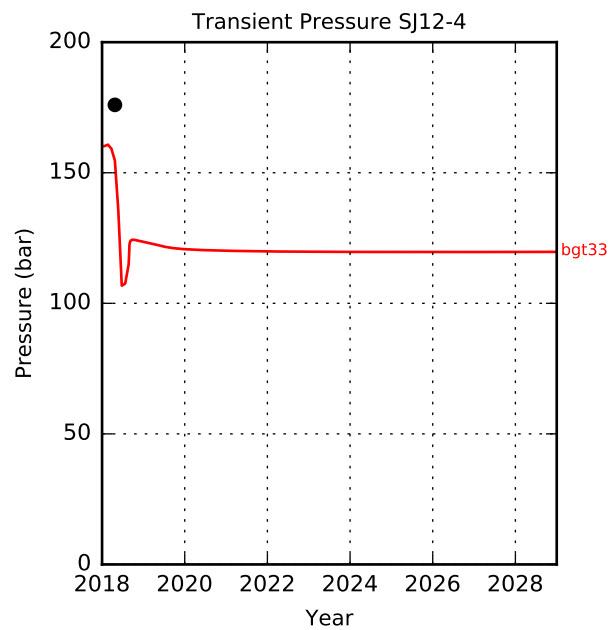
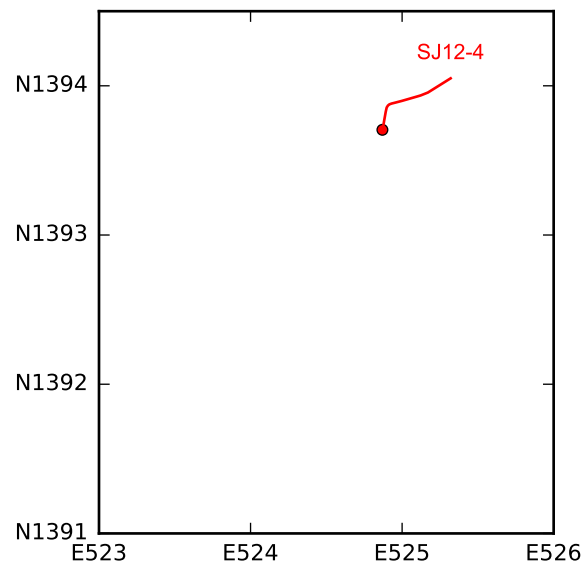
-700.0 masl	-1300.0 masl	-900.0 masl
-1700.0 masl	-1300.0 masl	-1100.0 masl



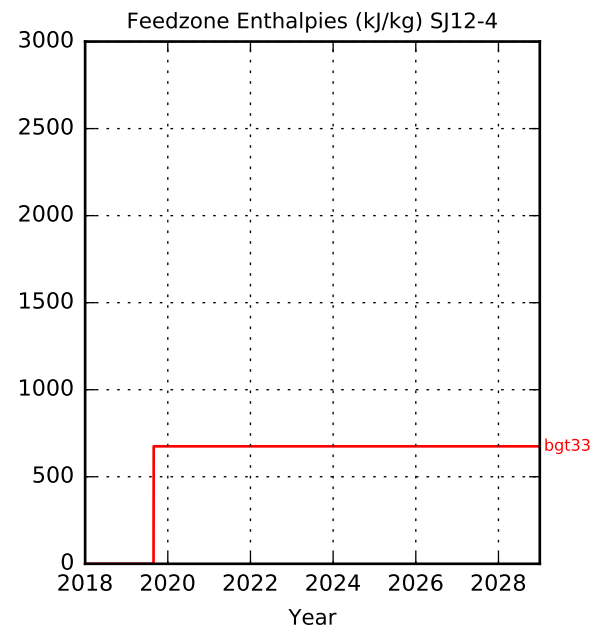
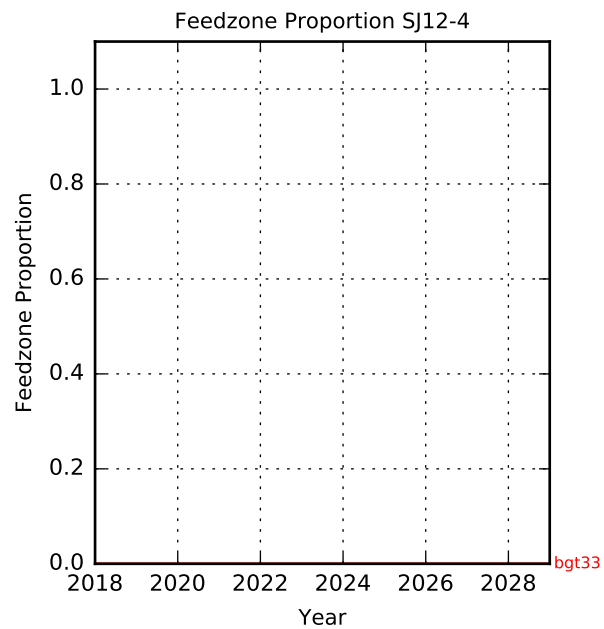
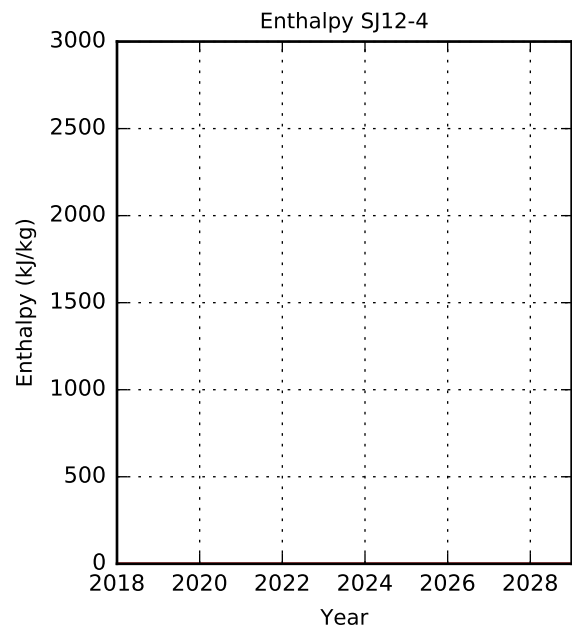
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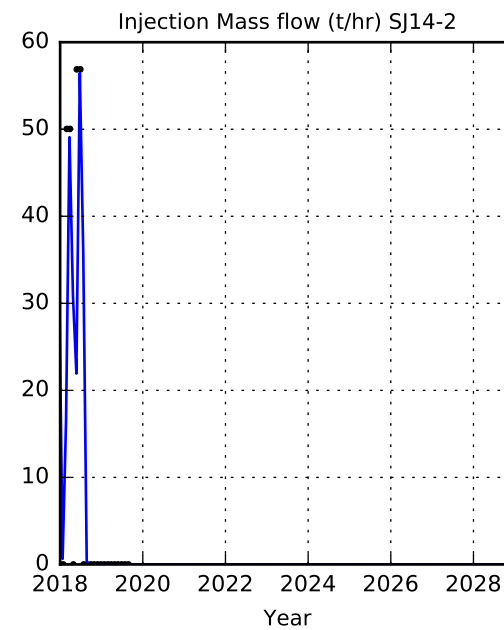
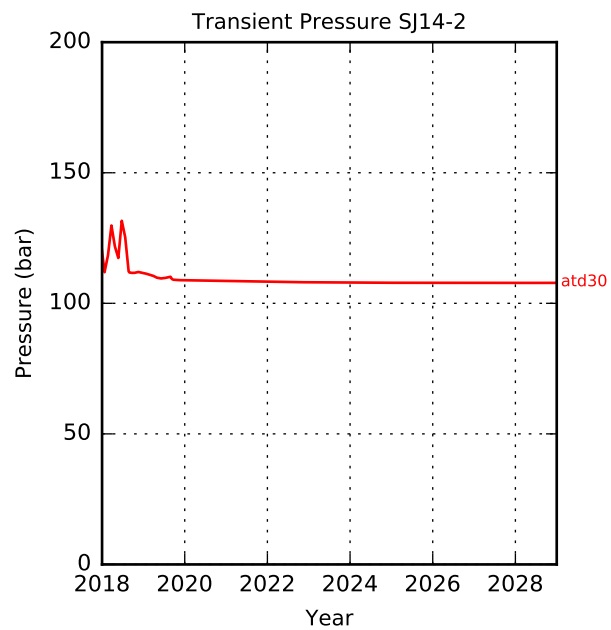
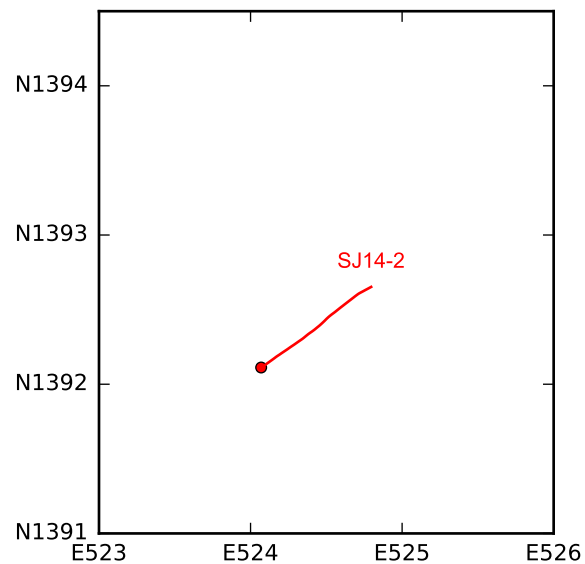






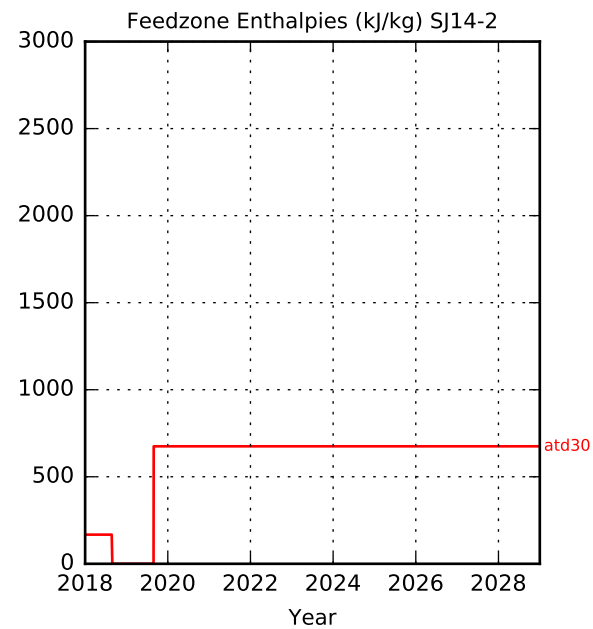
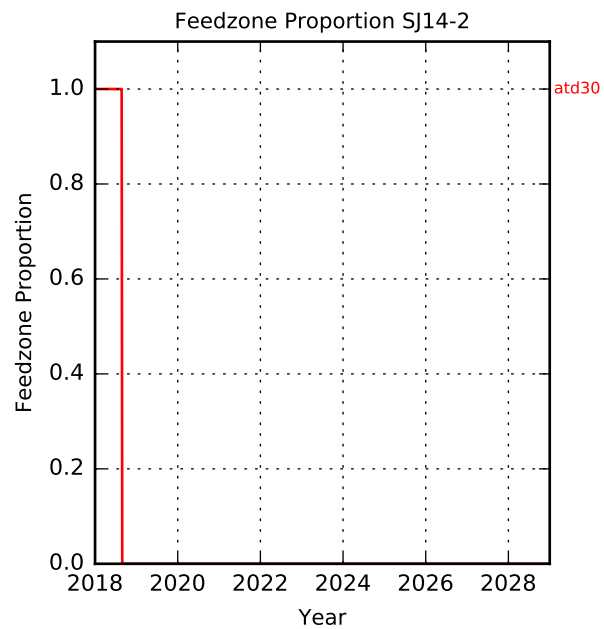
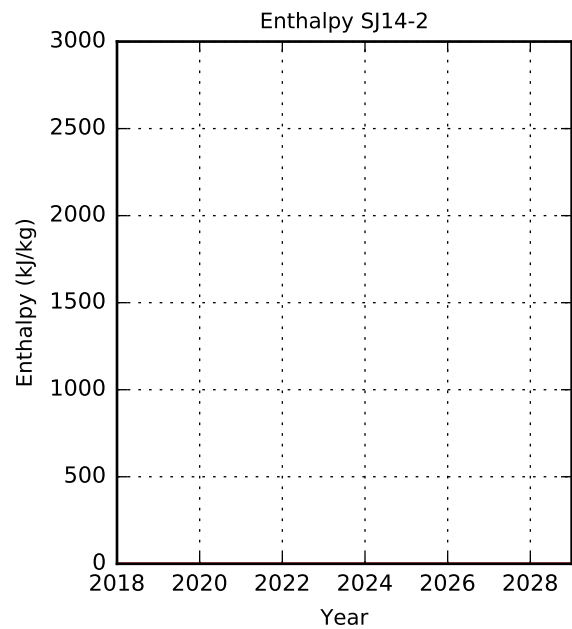
Feedzone Elevations
-2000.0 masl

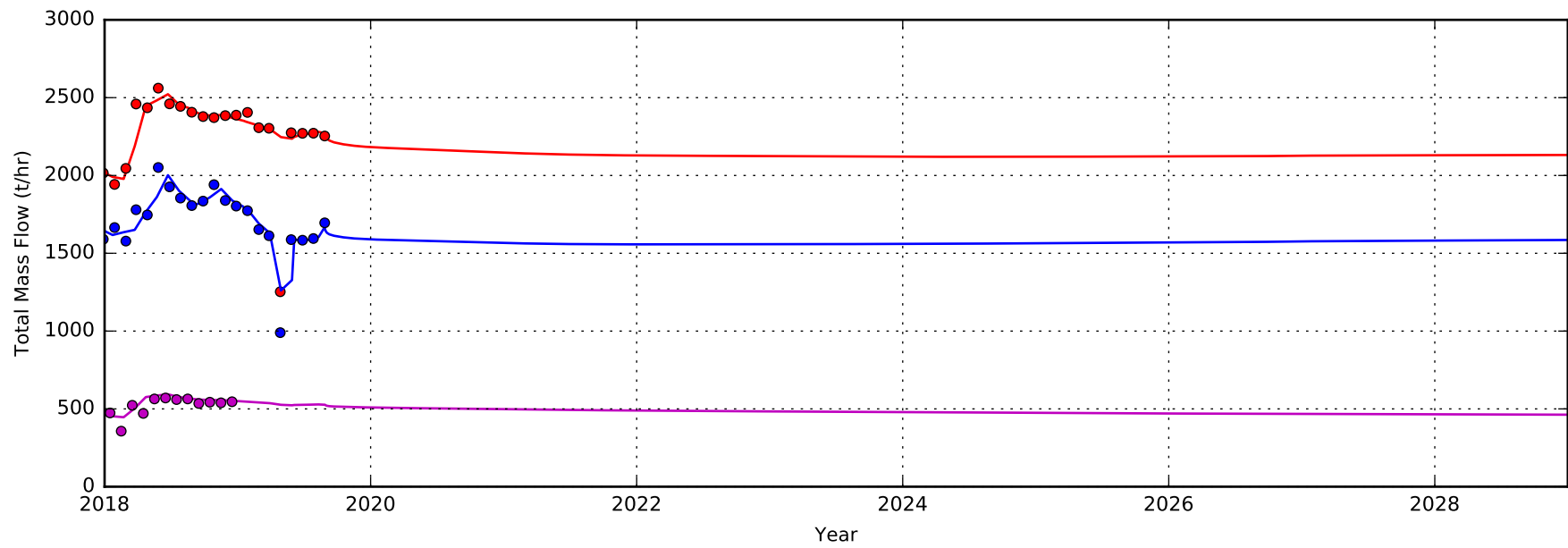




Feedzone Elevations

-1300.0 masl





— Total Production — Total Steam — Total Reinjection

