

# **Critique of the Applicant's Flood Risk Assessment for the Lime Down Solar Park**

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## **Introduction**

1. I am an Emeritus Professor of Geography and Environmental Science at the University of Reading. I have been involved in hydrological research since 1977, first as an environmental scientist in the electrical generation industry working on the effects of acid rain on freshwaters, and after he returned to academic life in 1999, working on modelling and monitoring freshwaters, and hydrology and climate change. I am a co-author of the standard paper on climate change and the water environment in England and Wales, and co-led the modelling work packages of two large EU-funded projects, EUROLIMPACS and REFRESH, which investigated the predicted effects of climate change on waters across Europe. My publications on hydrological topics have been referenced more than 1000 times. I live adjacent to the Lime Down area. The evidence I have produced is based upon my professional expertise, and is my true and professional opinion.
2. This report is a critical assessment of the quality of the Applicant's Flood Risk Assessment (FRA) for the Lime Down Solar Farm, compared to the requirements of planning policy. I have confined myself to the major issues and subjects within my expertise, i.e. hydrology rather than drainage.

## **Summary**

3. This paper describes and evaluates the Applicant's Flood Risk Assessment (FRA) for the Lime Down Solar Park, particularly in relation to the requirements of the Overarching National Policy Statement for Energy (EN-1). The project fails the Sequential Test, which aims to direct development away from flood-prone areas, since there are less flood-prone areas available. The Applicant attempts to justify this via the Exception Test, but fails in my view to meet either of the criteria required. The FRA meets only 6 of the 23 minimum requirements for a FRA mandated by EN-1 paragraph 5.8.15, and fails or partially fails to meet 17 of them. The assessment of fluvial flooding is seriously flawed: the Applicant ignores their own modelling which shows that an extreme event would cause devastating flooding, and concludes that the

flood risk is “negligible to low”. The FRA is overwhelmingly concerned with protecting scheme assets rather than people who live on- or off-site, and there is no attempt to assess the risks of surface water flooding to houses and transport infrastructure. For most of the site there is no dynamic modelling to evaluate flood duration and stream velocity – vital for predicting the effects of floods. Mitigation plans are vague and unspecific and there are no valid proposals for monitoring the effects of construction on local rivers. Data showing the sensitivity of the catchment to rainfall is ignored and the flood proneness of the area systematically downplayed. The Scheme will clearly increase the already high flood risk in the area and be difficult or impossible to mitigate. The analysis below sets out the evidence for these conclusions in detail.

## Legal and Policy Position

4. The UK is a wet country and flooding problems are widespread, and conversely the South of England is densely populated and is short of drinking water in dry years. Aquatic habitats are also highly valued and under threat from various sources of pollution. Any development which is likely to change the flow of water round the system thus needs to comply with a extensive legislation and guidance, as detailed by the Applicant in their Environmental Statement (ES) Chapter 11 [[APP-063](#)] Section 11.3. The most important policy is that set out in the national policy statements which apply to Lime Down, namely the Overarching National Policy Statement for Energy (EN-1); the National Policy Statement for Renewable Energy Infrastructure (EN-3); and for electrical cables, the National Policy Statement for Electricity Networks Infrastructure (EN-5).
5. The major statement of planning guidance is Section 5.8 of EN-1 covering flood risk. The policy recognizes that *“Although flooding cannot be wholly prevented, its adverse impacts can be avoided or reduced through good planning and management”* (5.8.2) and strives *“to ensure that flood risk from all sources of flooding is taken into account at all stages in the planning process to avoid inappropriate development in areas at risk of flooding, and to steer new development to areas with the lowest risk of flooding”* (5.8.6). The initial phase is the application of the *“Sequential Test”* (5.8.9), which aims to direct development away from

flood-prone areas. The Applicant has to demonstrate that the development could not reasonably be re-located into a lower flood risk area.

6. If and only if the Sequential Test cannot be met, then the development can still be consented if the “Exception Test” is passed. EN-1 states *“The Exception Test is only appropriate for use where the Sequential Test alone cannot deliver an acceptable site”* (5.8.10). The Exception Test allows a development where it is considered that the increased flood risk is outweighed by other benefits. The Exception Test requires the Applicant to demonstrate that:
  - a. Development that has to be in a flood risk area will provide wider sustainability benefits to the community that outweigh flood risk; and
  - b. The development will be safe for its lifetime taking account of the vulnerability of its users, without increasing flood risk elsewhere, and, where possible, will reduce flood risk overall.
7. The importance of not increasing flood risk elsewhere is again stressed in the next paragraph (5.8.12) which also emphasises that there should be no net loss of floodplain storage.
8. EN-1 goes on to consider consultations with statutory consultees and mitigation, including the requirements:
  - a. 5.8.26 Site layout and surface water drainage systems should cope with events that exceed the design capacity of the system, so that excess water can be safely stored on or conveyed from the site without adverse impacts, and
  - b. 5.8.27 The surface water drainage arrangements for any project should, accounting for the predicted impacts of climate change throughout the development’s lifetime, be such that the volumes and peak flow rates of surface water leaving the site are no greater than the rates prior to the proposed project, unless specific off-site arrangements are made and result in the same net effect.
9. The remainder of EN-1 5.8 consists of the criteria the Secretary of State must use for decision making, including (5.8.41):

“Energy projects should not normally be consented within Flood Zone 3b ..., or on land expected to fall within these zones within its predicted lifetime. This may also apply where land is subject to other sources of flooding (for example surface water). However, where essential energy infrastructure has to be located in such areas, for operational reasons, they should only be consented if the development will not result in a net loss of floodplain storage, and will not impede water flows.

10. The National Policy Statement for Renewable Energy (EN-3) says about flooding only that EN-1 must be followed and a flood risk assessment must be submitted. The FRA also needs to comply with the National Planning Policy Framework and local (Wiltshire) Flood Risk Management Strategy and policies. If there is a contradictory requirement, EN-1 will prevail, so it is taken here as the benchmark so as not to increase this paper to exorbitant length.

## The Flood Risk Assessment for Lime Down

11. The Applicant's Flood Risk Assessment (FRA) is summarized in the Environmental Statement Chapter 11, Hydrology, Flood Risk and Drainage [APP-063] and includes numerous supporting documents. Most important is Appendix 11-1 [APP-210] , prepared by consultants Arthian, which describes the rationale for the methods used. FRAs for individual sites, including the BESS and the cable route, are found in Appendices 11-2 [APP-211] to 11-9 [APP-218]. These all follow the same format. In addition Figures 11-1 to 11-8 [APP-135] to [APP-142] show maps of the flood risk of individual areas, consisting of the Environment Agency's fluvial and surface water flood risk maps superimposed on site maps. The Planning Statement [APP-267] contains substantial sections devoted to justifying the FRAs against planning policies. The Outline Construction Environment Management Plan [APP-277] contains a section on flood risk.
  
12. Chapter 11 sets out the assumptions of the FRA in Section 11.4. They start with the assumption that the Scheme will be low impact given that access roads and footways will be constructed with permeable material (11.4.1). The analysis does not then go on to test this assumption. The only justification given is that the analysis has been done this way in other projects. There is a lot of discussion of issues that do not conflict with this assumption, but other important considerations are omitted. Having made the assumption that the scheme will be of low impact, they unsurprisingly eventually conclude that the scheme will be of low impact. This is hardly an adequate analysis of a complex situation.
  
13. SLD has serious doubts that the FRA's conclusions on flood risk are reliable. It is noted that more than 700 local people have expressed concern about flooding in the Relevant Representations. Local experience is that flooding is a serious issue in many areas surrounding the scheme. Surface water flooding on local roads, sufficient to cause diversions, occurs every year. Fluvial flooding from the River Avon affects Malmesbury regularly, and a local flood relief scheme is being designed. The Gauze Brook is a tributary of the Avon which often floods Corston and the surrounding area. Large storms, such as Storm Bert in November 2024 and Storm Claudia in November 2025, not only flood the local area but the towns downstream. Storm Bert flooded the centre of Chippenham and substantial parts of Melksham and Bradford-on-Avon, and Storm Claudia flooded Malmesbury for a second time in a year, putting the financial viability of various sports clubs and other outfits at risk. The Environment Agency

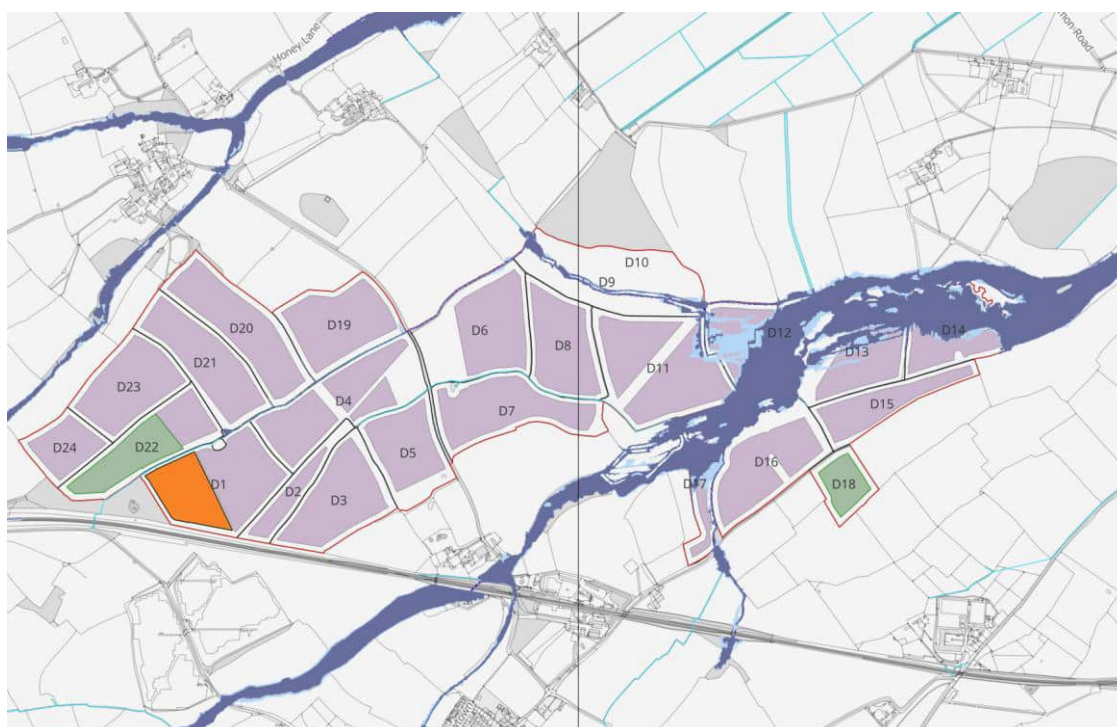
recognises that flood risk in Malmesbury (e.g. Whitlow 2020) and Bradford-on-Avon (EA 2025) is hard to mitigate.

### **The Sequential and Exception Tests**

14. NPS EN-1 *“steer[s] new development to areas with the lowest risk of flooding”* (para 5.8.6) and, where such infrastructure is *“exceptionally, necessary in flood risk areas... policy aims to make it safe for its lifetime without increasing flood risk elsewhere and, where possible, by reducing flood risk overall”* (para 5.8.7). The requirement that a development not precipitate *“increasing flood risk elsewhere”* is also part of the Exception Test to the Sequential Test (para 5.8.11). In determining the application, the Secretary of State should be satisfied that the Sequential Test was applied and satisfied as part of site selection and that a sequential approach was applied at the site level to minimise risk by directing the most vulnerable uses to the areas of lowest flood risk.
15. The Applicant has prepared a Sequential and Exception Test Report, appended to the Planning Statement. [\[APP-267\]](#) Annex C. The Sequential Test is applied in two stages: first in the selection of the Lime Down site as a whole compared to other sites (Section 3.2) and second in the selection of positions for infrastructure within the site (Section 4).
16. In relation to site selection, the Applicant sets out a consideration of 12 sites as prospective solar farm sites for a grid connection at Melksham. Maps of these in relation to flood risk are shown in Appendix A of Annex C in the Planning Statement, and a red-amber-green (RAG) analysis in Appendix B, with a red classification indicating a moderate or significant risk of flooding on the majority of the area; amber, that part of the area has a moderate or significant risk of flooding, and green, no documented risk. Most sites, including Lime Down, have an amber risk for both fluvial and surface water flooding. Sites 6, 7 and 8 have a red risk for both fluvial and surface water flooding and Site 11 a red risk just for fluvial flooding. Site 12, however, has a green risk for fluvial flooding. IGP justify the choice of Lime Down (Site 10) in relation to flooding on the grounds that it is lower risk than sites 6, 7, 8 and 11 and no worse than the other sites except for Site 12. However, there was no attempt to try and construct a scheme which would take the lower risk areas of Sites 1 -12 and combine parts of them into

a new scheme which would have other advantages, such as a much shorter cable to the grid connection, and generally lower environmental impacts overall.

17. In relation to the position of infrastructure within the site, the Applicant is required to apply a sequential approach at site level to the layout and design of the scheme to minimise flood risk to the Solar PV Sites by directing development to areas of lowest flood risk. It is noted that there are substantial areas of solar panels planned for Flood Zone 3, notably near the Gauze Brook upstream of Corston. See, for example, the Applicant's Flood Risk Map for Lime Down D [APP-139]:



18. Though the panels will be raised higher above ground in Flood Zones, there is photographic evidence that the flood risk has been underestimated in this area, and the panels may be partially submerged. There is therefore an increased risk that flooding of panel areas causes damage, resulting in the release of toxic materials from the panel interiors. There will also be conversion units in these areas containing components like transformers and inverters which can leak metals and hydrocarbons when damaged. This will be discussed in the report on Ground Conditions and Contamination.

#### Exception Test

19. IGP then went on to perform the Exception Test on the Lime Down site. Effectively this concedes that Lime Down does not meet the Sequential Test, because EN-1 makes it clear that *“The Exception Test is only appropriate for use where the Sequential Test alone cannot deliver an acceptable site”* (5.8.15). The Exception Test is performed to justify siting the development at Lime Down when an area of lower flood risk has been identified. Normally, the areas of high flood risk at Lime Down would make it unsuitable for development, but because of the policy preference for solar farms in Part 3 and Part 4 of NPS EN-1, development can be permitted if the Exception Test is passed.
20. In respect of the first criterion of the Exception Test, the Applicant’s Report in Section 5 of Annex C of the Planning Statement identifies wider sustainability benefits related to climate change adaption, job creation, economic benefits, skills training, landscape enhancements and habitat creation, biodiversity, accessibility, and flood risk. Those benefits are challenged by Stop Lime Down for the reasons set out herein and in other reports produced on behalf of Stop Lime Down.
21. The second criterion of the Exception Test states that *“the project will be safe for its lifetime taking account of the vulnerability of its users, without increasing flood risk elsewhere, and where possible will reduce flood risk overall”*. I have prepared a separate report which comments upon the increased risk of flooding which will be caused by the scheme, both on-site and off-site. In brief, the scheme will increase surface water runoff rates as a consequence of runoff from solar panels and the Applicant’s flood risk assessment does not properly take this risk into account. Essentially, the Applicant has relied on an untested model to assert that the existing ground can absorb the concentrated runoff from the panels, and failed to take into account more modern research, the nature of the catchment soils and the effects of the large tracking panels. The Applicant’s Flood Risk Assessment fails to propose adequate mitigation to reduce the flood risk, especially as runoff has been underestimated. There is no consideration of the vulnerability of users (numbers of houses at risk, for instance). Flood risk off site will increase because of the increased runoff velocity and amount. As a consequence, the second criterion of the Exception Test is not met.

## Fluvial Flooding

22. Generic flood risk assessment methodology is described in Appendix 11-1 [[APP-210](#)], Sections 3 to 6. The methodology is applied in detail in the FRAs for the individual sites, as set out in the following documents:

- a. Appendix 11-2 – Lime Down A [**APP-211**]
- b. Appendix 11-3 – Lime Down B [**APP-212**]
- c. Appendix 11-4 – Lime Down C1 [**APP-213**]
- d. Appendix 11-5 – Lime Down C2 [**APP-214**]
- e. Appendix 11-6 – Lime Down D BESS [**APP-215**]
- f. Appendix 11-7 – Lime Down E1 [**APP-216**]
- g. Appendix 11-8 – Lime Down E2 [**APP-217**]
- h. Appendix 11-9 – Lime Down Cable Route Corridor [**APP-218**]

23. All these reports follow the same format with only minor variations. All reports conclude that unmitigated flood risk is “*negligible to low*” in the studied area. Accordingly, this report considers those appendices collectively. As noted above, SLD has serious doubts in respect of the reliability of the FRA’s conclusions on flood risk.

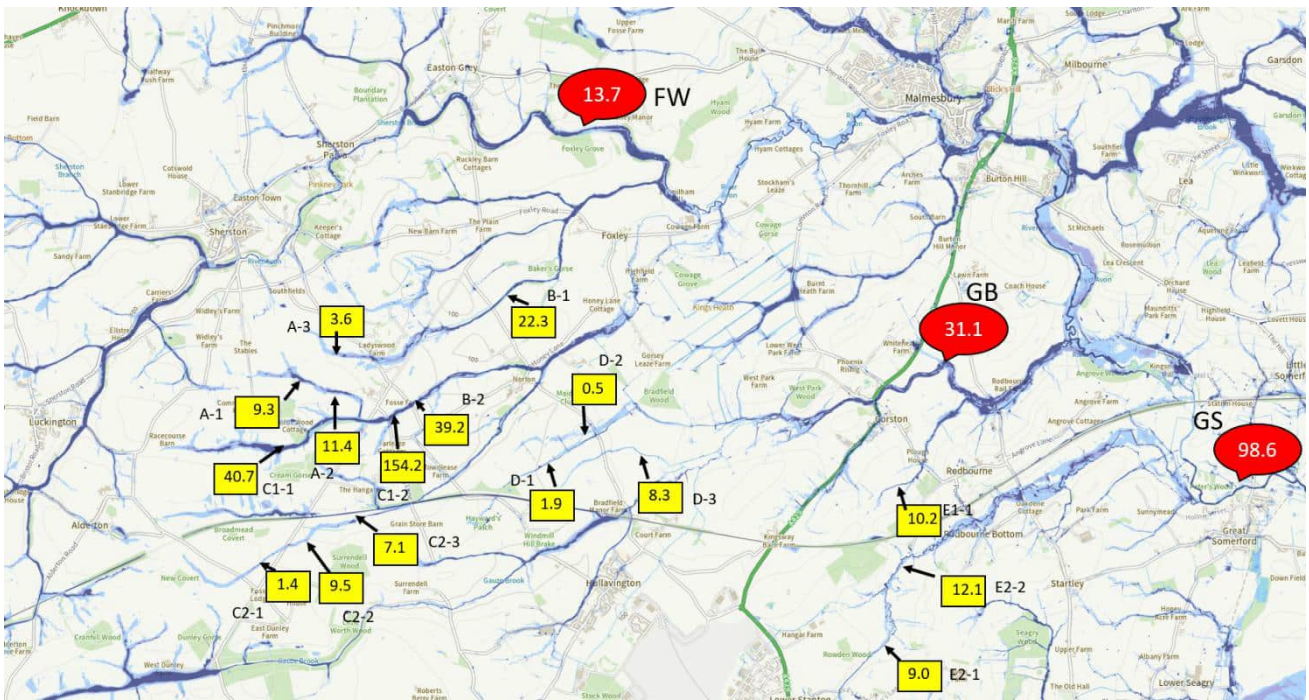
24. The FRA starts by considering fluvial flooding. Fluvial flooding requires the presence of a watercourse of some sort. Some of the panel areas do not have recognised main rivers (regulated by the EA) or ordinary watercourses (regulated by Wiltshire CC as the Lead Local Flood Authority), but all have drainage channels and the FRA correctly considers these as potential sources of fluvial flooding as well.

25. Flows in a selection of channels are estimated for an extreme flow event, the EA’s 0.1% Annual Exceedance Probability FMfSW event, for which maps and data are available. Some parts of the text say the modelled event is the 1% AEP event (e.g. Appendix 11-1, 7.1.7; Appendix 11-2, 2.3.7 and similar paragraphs in Appendices 11-3 to 11-8) – I assume this is a mistake as the modelling then goes on to discuss the 0.1% event. Flows are calculated using Manning’s open channel flow formula, which is parameterised for the channel concerned using EA LIDAR data, and presented in Annex B of each site FRA. It is acknowledged that using Manning’s formula, which was developed for regular, man-made structures, introduces uncertainties, but it is

asserted that it is a practical solution in the absence of more detailed modelling. The descriptions of the process in the main text and the Annex B are confusing and contradictory. In the text it states that the EA's mapping of the extent of flooding of this event "*is referenced for context only and was not used as an input to the calculation*". In Annex B it states "...the extents of the EA surface water flood map (0.1% AEP event, present day) have been compared to underlying LiDAR data to provide an estimate of water levels...". In other words, the EA's mapping *is* used as input to the calculation, and it is difficult to see how the analysis can be done otherwise. Having calculated flows for this event, a second set of flows is calculated using the EA's climate change uplift for the area, by increasing the calculated flows by 71%.

26. These calculated flows are given before the Manning's tables in Annex B for each site, but the results are never discussed or included in the assessments. The assessments ignore the modelling and go on to conclude that the fluvial flood risk is "low" in every case. In fact, the modelling indicates that fluvial flooding in an extreme event would be devastating as discussed below. In terms of the Applicant's Impact Assessment Methodology set out in Chapter 11 of the ES, Tables 11-3 to 11-5, the impact magnitude should be "high", the sensitivity should be "high" as there are residential properties at risk downstream, and the significance should thus be "major".

27. The results of the modelling of fluvial flooding at each site using Manning's method, as described in Annex B of each site-specific FRA (Appendices 11-2 to 11-8), are collected together in Figure 1.



**Fig. 1. Modelled flows in  $\text{m}^3 \text{s}^{-1}$  during the 0.1% AEP EA FMfSW event (yellow rectangles). Site numbers are shown adjacent, the letter indicating the Lime Down area being drained. For context, red ovals show peak flows in  $\text{m}^3 \text{s}^{-1}$  during Storm Bert in 2024 at official gauging stations: Fosse Way (FW) and Great Somerford (GS) on the mainstream Avon and the Gauze Brook (GB). The base map is the EA's pre-2025 surface water flooding map.**

28. The calculated flows are enormous for small, mostly ephemeral, streams and drainage ditches. For context, peak flows from an exceptional storm, Storm Bert, in November 2024 are shown at the three official river gauging stations in the area. Storm Bert rainfall had a 40-year return period and caused serious flooding not only locally but downstream in Chippenham, Melksham and Bradford-on-Avon. For the Gauze Brook this was the highest flood peak on record: for Fosseway and Great Somerford, the second highest (see separate paper on Storm Bert). Peak flows in the main River Avon during Storm Bert are comparable with the modelled flows in the small Lime Down streams during the 0.1% AEP event (Fig.1). Site C1-2 has the highest modelled flow at  $154.2 \text{ m}^3 \text{s}^{-1}$  ( $264.7 \text{ m}^3 \text{s}^{-1}$  with climate change uplift). This stream runs into the Avon near Foxley. We know from Storm Bert that a flow in the Avon of  $13.7 \text{ m}^3 \text{s}^{-1}$  at Fosseway near Foxley caused serious flooding issues (Fig. 1). With a flow of  $154.2 \text{ m}^3 \text{s}^{-1}$ , more than 10 times greater, the devastation would be very significant indeed. As well as unprecedented flooding, bridges would be swept away (one bridge was lost to Storm Bert), houses in Corston and Malmesbury would be flooded or destroyed altogether, stream channels would be converted into deep gullies and vast amounts of sediment transported

downstream. And that is without any contribution from the rest of the Avon Catchment, which is much larger (89.7 km<sup>2</sup> at Fosseway - all hydrological data are from the National River Flow Archive and the EA's hydrological data explorer portal).

29. In fact, 154.2 m<sup>3</sup> s<sup>-1</sup> is not a credible value for discharge in a drainage ditch. The average discharge of the Thames at Kingston on Thames is only 65 m<sup>3</sup> s<sup>-1</sup>. There are more indications that the modelling is unreliable. About 100 m downstream at Site B2, modelled discharge in the same stream as C1-2 has dropped to 39.2 m<sup>3</sup> s<sup>-1</sup>, itself a ludicrously high value. There are no potholes which could swallow such a quantity of water. Fig. 1 shows that the modelled values have a large scatter for no apparent reason, even where they are not self-evidently too high. All this calls the accuracy of the whole Manning's modelling effort into question.
30. Irrespective of that, the Applicant can only claim that the risk of fluvial flooding is "low" by ignoring their own modelling. Neither the Hydrology chapter of the ES [APP-063] or the covering flood risk report (Appendix 11-11 [APP-210]) define a flood risk scale, so the meaning of "low" is imprecise. No explanation is provided of how a rating of "low" was derived. PPG (Flood risk and coastal change) states that "'Flood risk' is a combination of the probability and the potential consequences of flooding" (para 001), though there is no guidance on how to combine them. In this case the Applicant is modelling the 0.1% AEP event, which is by definition low probability, but the consequences are very severe. In my opinion, it is misleading to describe this result as "negligible to low". Having observed the severe consequences, the Applicant should have modelled a higher probability event such as the 1% AEP event, which is the normal design flood in any case, and considered the consequences of that. To that extent, the FRA fails to consider the reasonable worst case scenario and the likely effects of the scheme.
31. The EA's fluvial flooding maps show that fluvial flooding is a risk in parts of all the sites, and the modelling, such as it is, shows the risks are considerable. This is surprising given the underlying limestone geology, and the reason is probably the low permeability of parts of the site both from soils and the Forest Marble rock formation in its mudstone facies.
32. For two of the sites, although the same approach is taken for smaller watercourses, more detailed modelling of fluvial flooding by larger streams was performed. The Eastern side of

Area D has significant areas in Flood Zones 2 and 3 due to the topography and the presence of the Gauze Brook. Hydraulic modelling of the Gauze Brook was undertaken for a number of scenarios. Results are presented showing flood depths across the panel areas, the conclusion being that the flood hazard was predictable, of low magnitude and able to be mitigated (Appendix 11-6, 2.3.6 to 2.3.12). While a hydraulic model is a more robust approach than using Manning's equations, there are several problems with the approach taken:

- No detail whatever is given of the model used or how it was parameterized. The quality of the results thus cannot be assessed.
- Analysis of photographs of the effects of Storm Bert in the area upstream of Corston show a flooding extent greater than that calculated by the model even for the 0.1% AEP + 31% climate change scenario. Storm Bert had a roughly 50-year return period (2% AEP), so this indicates that the model is underestimating flooding.
- The results are concerned exclusively with preventing damage to the Applicant's infrastructure, and thus only flood depths and extent in the panel areas are calculated. The effects on people living nearby, the transport infrastructure and flooding off-site are totally ignored. This would require modelling of outputs such as speed of onset, velocity, hazards off site and duration, as required by EN-1 (see below).
- The only modelling of the effects of the panels themselves is the self-evident calculation that the volume of panel legs does not significantly reduce floodplain storage volume. This is related to the Applicant's false assumption that the panels have no hydrological effects (see report on panel runoff).
- There are assertions that the BESS and 400 kV substation, which are in Area D, will not be affected by flooding, but none of the modelling results presented show these areas.

33. Parts of Lime Down E situates panels in areas with medium and high levels of flood risk (i.e. Flood Zones 2 and 3). This is due to the area's close location to Gabriel's Well stream. This stream is identified by the Environment Agency as "Rodbourne Brook". It is nameless on OS maps. Confusingly, the Applicant uses both names in Appendix 11-8. In this case, the EA's National Flood Risk Assessment 2 (NaFRA2) model superimposed on LIDAR data is used to predict flood risk and depths for the years 2040 to 2060. Here there is a defined model, but as before, the assessment is concerned exclusively with the Applicant's assets and not the risks to local people or off-site flooding. There is no modelling of speed of onset, flow

velocities, duration, or off-site hazards which would be needed for such an assessment, as required by EN-1.

34. The Applicant throughout attempts to downplay the flood sensitivity of the area. The FRAs all have a paragraph saying *“There is no Site-specific information in third-party reports regarding fluvial flood risk at Lime Down [Site A to E] or in the immediate vicinity”* (e.g. Appendix 11-4, 2.3.4). In Annex C of the *same document*, all the FRAs reproduce a letter from the Environment Agency saying they have records of fluvial flooding in the area in 1925, 1932, 1954, 1979, 1999, 2007, 2009, 2012, and 2013, which totally contradicts the earlier statement. There is an extensive literature on flooding in the local area which even a superficial search would have revealed. For instance, the consultant’s report on the Malmesbury Community Flood Defence Scheme (Whitlow, 2020) has a list of 38 major floods in Malmesbury between 1880 and 2020.
35. The BESS area is subject to a separate drainage assessment in Appendix 11-6, Section 3. In contrast to much of the rest of the report, this is more detailed, and includes specific suggestions about technology. Drainage from the area will be discharged direct to the Gauze Brook, with the rate limited to  $8.64 \text{ l s}^{-1}$  by water storage.

### **Surface Water Flooding**

36. The FRAs conclude that *“there is no evidence within relevant third-party reports... to suggest that Lime Down [Site A to E] has historically experienced surface water flooding”* (e.g. Appendix 11-3, 2.4.5). As noted above, this is contrary to local experience of the area, where surface water flooding is experienced every winter. Appendix 11-1, 1.3.1 identifies four sources relied upon for this statement, two being the EA Flood Map for Planning and the second being the EA Long Term Flood Risk Map. The FRA also refers to the British Geological Survey Interactive Map and DEFRA’s MAGIC Interactive map, although neither contain any information on flooding different from the EA maps.
37. The site FRAs conclude that most of the areas are at low risk of surface water flooding, and where there are patches of higher risk, the predicted depths are not enough to constitute a danger to equipment. Where this might be the case, equipment will be waterproofed and raised above the predicted flood level by 0.6m. As with fluvial flooding, the focus is largely on

protecting the Applicant's assets rather than the people who live in the area. Local knowledge suggests that the risks to assets are underestimated, particularly on the Gauze Brook upstream of Corston. The Exception Test requires that "The project will be safe for its lifetime taking account of the vulnerability of its users, without increasing flood risk elsewhere, and, where possible will reduce flood risk overall." Given the projected effects of climate change, and the absence of any modelling other than for flood depth, the Applicant has not demonstrated that the project will be safe for its lifetime. It will also in my view increase flood risk elsewhere (see reports on panel runoff and increased water in the panel areas).

38. Though there is less public information on surface water flooding than fluvial flooding, I shared my report on Storm Bert, which included pictures of surface water and fluvial flooding in all Lime Down areas, with consultants Arthian (then known as Mabbetts) in an early stage of the Lime Down process, which they acknowledged. As with fluvial flooding, there appears to be a systematic attempt to downplay the flood susceptibility of the area. The main issue here, which the FRAs do not deal with at all, is the effect of surface water flooding on the houses of people who live in the area, and on the transport links (roads, railways, and PROWs) which cross the area, and how the solar farm will affect these.

### **Mitigation and Residual Risk**

39. The FRAs define a residual risk as "*an exceedance event, such as the 1 in 1000 year (0.1% AEP) flood event that would overtop the [drainage of the site concerned]. As the probability of a 1 in 1000 year flood event occurring is 0.1% in any given year, the probability is low and, therefore, no additional mitigation beyond the embedded mitigation measures of the Scheme is required*". In other words, a residual risk is a low probability, high flow event, but because it is low probability it can be ignored. This reasoning is fundamentally flawed and contrary to the purpose of flood risk analysis: it is precisely the low-probability, high-consequence events that flood assessment exists to address, and which EN-1 requires to be assessed.

40. Residual risk and how to tackle it is defined in EN-1 paragraph 5.8.15, which states that the FRA should:

*“Include the assessment of the remaining (known as ‘residual’) risk after risk reduction measures have been taken into account and demonstrate that these risks can be safely managed, ensuring people will not be exposed to hazardous flooding; consider how the ability of water to soak into the ground may change with development, along with how the proposed layout of the project may affect drainage systems.”*

41. The FRA fails to properly identify the mitigation considered necessary for dealing with residual flooding risks. The FRAs simply refer to the covering report (Appendix 11-1) which has a list of mitigation options which *could* be applied. These include only building sensitive infrastructure in low flood risk zones; elevating equipment in flood risk areas above the predicted flood level; eight metre buffer strips around watercourses (although it is not clear what will count as a watercourse); infiltration trenches around structures (such as conversion units) which sit on hardstanding and directing runoff to permeable SuDS features *“where practicable”*. The latter raises the issue of what happens when it is not practicable and who decides what is practicable; and only allowing site access on permeable tracks. As noted above, many of these are designed to protect scheme assets rather than *“ensuring people will not be exposed to hazardous flooding”* (EN-1, 5.8.15).

42. It is also notable that no mitigation is proposed for runoff from the panels themselves. My concerns in respect of solar panel runoff are addressed in a separate paper.

### **Water Quality and Pollution Control**

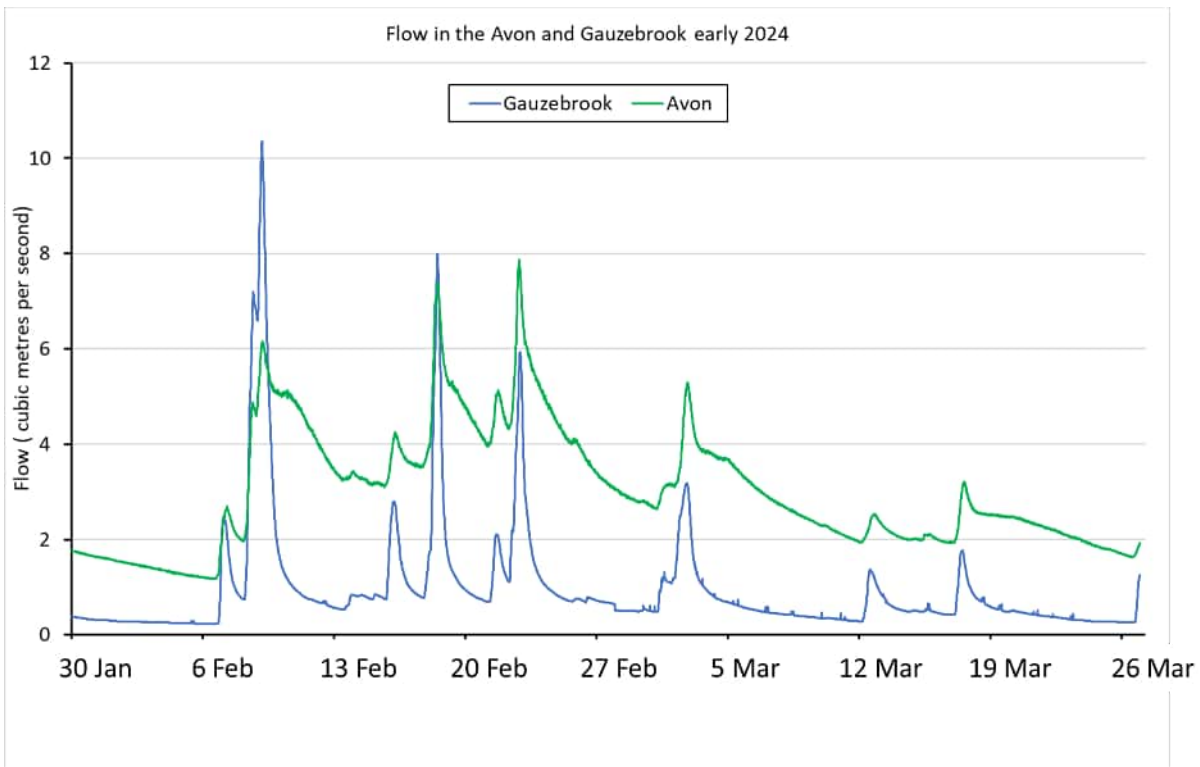
43. Appendix 11-1 [APP-211], but not the site-specific FRAs, considers measures to protect water quality, mostly during construction. The measures reflect standard practice and should help to control some of the pollution issues if implemented thoroughly. The principal issues considered are the generation of silt-laden runoff and spillages and leaks.

44. There are some more contentious issues, however. Appendix 11-1 recognises that runoff from the panels is likely to generate silt-laden runoff [APP-211]. It is suggested that planting of a grass sward under the panels will be enough to mitigate it. I address my concerns in respect of solar panel runoff and proposed mitigation measures in a separate report. In short, there is no evidence that the Applicant’s proposed planting would be effective.

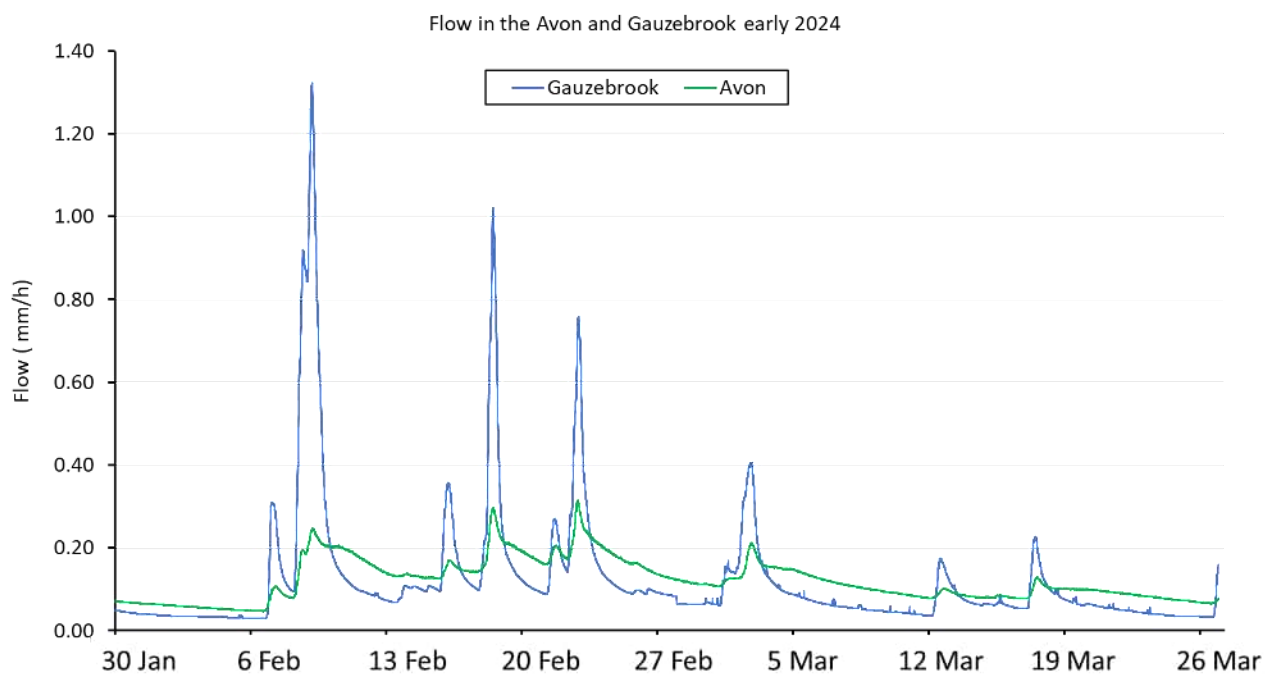
45. Monitoring the effects of construction of the Scheme is another aspect which is inadequately covered. Appendix 11-1, 3.2.1 states: “...a Water Management Plan (which will form part of a detailed CEMP) will include details of pre-construction, construction, and post-construction water quality monitoring. This will be based on a combination of visual observations and reviews of the Environment Agency’s automatic water quality monitoring network”.
46. Visual observations are inadequate since pollution episodes can occur anywhere and anytime, including at night, be of short duration and may not be visible in any case. The Environment Agency Automatic Monitoring Network does not exist at present, and the EA makes no routine automated measurements in the Lime Down area. Adequate monitoring would mean setting up monitoring stations in key locations for at least two years before construction starts, and continuing to monitor throughout the life of the project. Presently, therefore, the Applicant has no proposal for managing pollution effects after construction..

### **The Need for Dynamic Modelling**

47. As EN-1 mandates (Table 1 below) a minimal FRA should include information on speed of onset, velocity, hazard, and duration of flood events that affect an area. IGP’s FRA does not even attempt this. The data to do so are readily available. Figure 2 shows the response of two local rivers at their respective flow gauges to some routine storm events in early 2024. Although the Gauze Brook catchment is much smaller than the Avon’s, the size of the flood peak for the first two events is actually greater in the Gauze Brook. The Gauze Brook has a faster speed of onset and recession but shorter duration than the Avon. This is easier to see if the same events are presented normalised to unit catchment area, by expressing them in  $\text{mm h}^{-1}$  (Fig. 3).



**Fig. 2 Discharge in  $\text{m}^3\text{s}^{-1}$  in the Gauze Brook and mainstream Avon at Fosseway in early 2024. Data from DEFRA’s Hydrology Data Explorer portal**



**Fig. 3: As for Fig.2, but expressed in  $\text{mm h}^{-1}$ .**

48. The relatively rapid response to rain events and relatively high flow peaks in the Gauze Brook are evident. The Gauze Brook can act as surrogate for the ungauged streams in the Lime Down area, such as Rodbourne Brook (Gabriel’s Well), Norton Brook and various un-named

watercourses on the same geology. This is not flood modelling, but observed data which shows how the area is at risk from any increase in runoff volumes and velocities, since flooding is directly related to peak heights. It is these peaks which generate the frequent flooding which is so familiar to residents of Corston and the smaller communities in the area.

49. This rainfall sensitivity is greater than would be expected for a limestone area. It is probably due to the low infiltration rates across the area, but also to a relatively low water storage capacity in the soils and aquifers. The detailed report on the Malmesbury Groundwater Scheme (Colley, 2017) mentions these mechanisms as an explanation of the “flashiness” and proneness to flooding of the Bristol Avon in the area.

50. The effects of this sensitivity can only be predicted using dynamic hydraulic modelling, and not mere prediction of flood depths. In this respect, the Applicant’s FRA is completely inadequate in capturing the risks to the people of the Lime Down Area and downstream, and to transport links and PRowS.

### Comparison with Planning Requirements

51. Table 1 assesses whether the Lime Down FRA, as described in the Environmental Statement, meets the minimum requirements for FRAs in the Overarching National Policy Statement for Energy (EN-1), paragraph 5.8.15. It demonstrates that the Lime Down FRA meets only 6 of the 23 minimum requirements mandated by EN-1, and fails or partially fails to meet 17 of them.

EN-1 Minimum Requirements. The FRA should...	Meets Requirements?
be proportionate to the risk and appropriate to the scale, nature and location of the project	No. For a large-scale, high-risk project in a sensitive location, too many important factors are deficient. These include: flawed modelling of fluvial flooding, which is ignored by the Applicant in assessing risk; the FRA is overwhelmingly concerned with protecting scheme assets rather than people who live on- or off-site; failure to assess the risks of surface water flooding to houses and transport infrastructure; no dynamic modelling which might evaluate flood duration and stream velocity; mitigation plans are vague and unspecific; there are no valid proposals for monitoring the effects on local rivers; and other matters mentioned in the text
consider the risk of flooding arising from the project in addition to the risk of flooding to the project	No. Risks to the project are discussed, but flooding arising from the project is hardly considered. Apart from the minor matter of the volume of the legs of the solar panels, the Applicant simply assumes it is not going to occur.
take the impacts of climate change into account, across a range of climate scenarios, clearly stating the development lifetime over which the assessment has been made	Yes.

be undertaken by competent people, as early as possible in the process of preparing the proposal	Yes.
consider both the potential adverse and beneficial effects of flood risk management infrastructure, including raised defences, flow channels, flood storage areas and other artificial features, together with the consequences of their failure and exceedance	No. Little or no discussion of any of this. Flood management infrastructure is mentioned, but there are no specific plans, assessments of the amount required and whether it can be accommodated on site, or discussion of the consequences of exceedance.
consider the vulnerability of those using the site, including arrangements for safe access and escape	Yes.
consider and quantify the different types of flooding (whether from natural and human sources and including joint and cumulative effects) and include information on flood likelihood, speed-of-onset, depth, velocity, hazard and duration	No. Different types of flooding are considered, but no consideration of joint or cumulative effects, nothing on speed of onset, velocity, hazard or duration.
identify and secure opportunities to reduce the causes and impacts of flooding overall, making as much use as possible of natural flood management techniques as part of an integrated approach to flood risk management	No. As it is assumed that the increase in flood risk will be minimal, little consideration has been given to reducing the impacts of flooding except round the BESS area.
consider the effects of a range of flooding events including extreme events on people, property, the natural and historic environment and river and coastal processes	No. Nothing on this at all. The Applicant has failed to demonstrate how impacts would be avoided or minimised.
include the assessment of the remaining (known as 'residual') risk after risk reduction measures have been taken into account and demonstrate that these risks can be safely	No. Residual risks are not assessed; they are simply assumed to have been mitigated by a set of possible measures. There can be no

managed, ensuring people will not be exposed to hazardous flooding	confidence that people will not be exposed to hazardous flooding.
Describe the existing surface water drainage arrangements for the site	Yes. In outline, but probably adequate.
Set out (approximately) the existing rates and volumes of surface water run-off generated by the site. Detail the proposals for restricting discharge rates	No. No information on existing rates and volumes. Proposals for restricting discharge only for the BESS.
Set out proposals for managing and discharging surface water from the site using sustainable drainage systems and accounting for the predicted impacts of climate change. If sustainable drainage systems have been rejected, present clear evidence of why their inclusion would be inappropriate.	Yes. But proposals are vague and in outline only. SuDS systems are not rejected.
Demonstrate how the hierarchy of drainage options has been followed.	Yes.
Explain and justify why the types of SuDS and method of discharge have been selected and why they are considered appropriate	No. All options for SuDS types are left open.
Explain how sustainable drainage systems have been integrated with other aspects of the development such as open space or green infrastructure, so as to ensure an efficient use of the site.	No. No information about the spatial distribution or design of SuDS schemes.
Describe the multifunctional benefits the sustainable drainage system will provide.	No.
Set out which opportunities to reduce the causes and impacts of flooding have been identified and included as part of the proposed sustainable drainage system.	No.

Explain how run-off from the completed development will be prevented from causing an impact elsewhere	No. It is simply assumed that there will not be any excess runoff.
Explain how the sustainable drainage system been designed to facilitate maintenance and, where relevant, adoption. Set out plans for ensuring an acceptable standard of operation and maintenance throughout the lifetime of the development.	No. Any plans that may exist are not presented. Only vague outline statements are available in the Outline Construction Environmental Management Plan, and reference made to a Water Management Plan which has yet to be produced.
detail those measures that will be included to ensure the development will be safe and remain operational during a flooding event throughout the development's lifetime without increasing flood risk elsewhere	No. Some of this is mentioned but the issue is not specifically discussed. The placing of panels in high flood risk areas raises questions over whether the scheme could operate in a flood event and its stability over a 60-year period.
identify and secure opportunities to reduce the causes and impacts of flooding overall during the period of construction	No. Some measures are discussed, but there is no integrated statement.
be supported by appropriate data and information, including historical information on previous events.	No. Very little data is presented. Historical research is limited to the Environment Agency's historical flood maps, which are incomplete. There is a large amount of unused information on flooding in the Bristol Avon catchment.

**Table 1: Minimum FRA requirements according to EN-1, paragraph 5.8.15 (left column) and whether the Lime Down FRA meets those requirements (right column).**

## Conclusions

52. This assessment shows why the Applicant's FRA fails to register the observed sensitivity of the Lime Down area to flooding, and why it is inadequate in predicting the response of flooding to the construction of the solar farm. Current flood risk is assessed by considering only the EA's fluvial and surface water flooding maps. Any other information on the hydrological

characteristics of the local area such as data from river flow gauges, infiltration rates and groundwater investigations is ignored. The assessment is concerned overwhelmingly with risks to the Scheme's assets and not the risks to local people on or off site. The EA's flood maps are suitable for this, and allow sensitive infrastructure to be sited away from the highest risk areas. But people who live in houses in vulnerable locations, or use roads which cross flood-prone areas, are not in the position of being able to move the houses and roads somewhere else. The EA's maps show that houses and roads *are* subject to flood risks, exactly as local people observe, accounting for the widespread concern expressed in the RRs. In this and other documents I present evidence that the Scheme will exacerbate the existing flood risk. But the FRA contains no assessment of the numbers of houses or lengths of highway at risk – only the Applicant's own assets.

53. The Scheme fails the Sequential Test aimed at steering development away from flood-prone areas, since there are less flood-prone areas available. The Applicant attempts to justify this via the Exception Test, but in Stop Lime Down's view it fails to meet either of the criteria required.
54. The FRA fails to address many of the minimum requirements for a FRA under NPS EN-1. As a result, it is difficult to judge the actual flood risk due to the Scheme, as so much information is missing. It is clear from first principles, however, that the Applicant's FRA seriously underestimates the increase in flood risk, particularly off site.
55. There appears to be a systematic attempt to downplay the flood sensitivity of the area. The Applicant's own modelling shows that an extreme rainfall event would be devastating locally and downstream due to fluvial flooding, whereas the assessment ignores the modelling and concludes that the risk of fluvial flooding is "low". The EA points out that they have records of frequent fluvial flooding in the area, and the assessment quotes this but still manages to conclude that there are no records of fluvial flooding in the vicinity of the sites.
56. The Applicant recognises that mitigation is required around the hard surfaces introduced into the catchment, but the proposed mitigation is generally a list of possible actions rather than a plan. There is no assessment of the nature and size of the SuDS features which would be required, whether there is enough space for them, and the effects on the landscape. Only

around the BESS is there what appears to be an adequate outline drainage plan. Additionally, it is assumed that runoff from the panels themselves will require no mitigation. A separate paper will demonstrate why such mitigation is needed.

57. Even a cursory look at river flow data shows the sensitivity of the area to rainfall events, and that hydraulic modelling is needed to assess it. If the Scheme is built on the basis of the Applicant's FRA, its deficiencies will leave people in the area vulnerable to enhanced and serious flooding, and impose significant costs on the local and national flood protection authorities.

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# MALMESBURY GROUNDWATER SCHEME: RESTORING SUSTAINABLE ABSTRACTION

Environmental assessment in support of application to vary  
Wessex Water abstraction licences

Final report  
DECEMBER 2017



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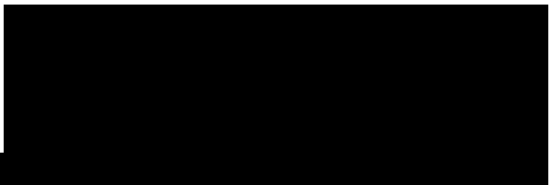

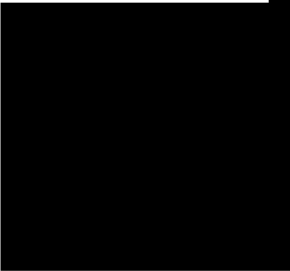

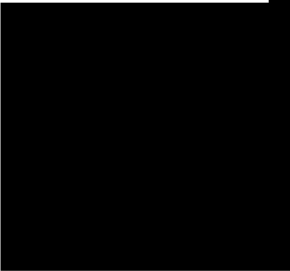
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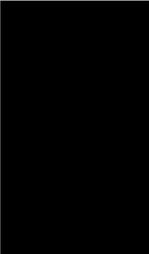
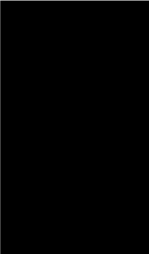
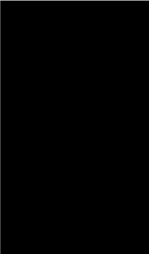
Cover photo: Sherston Avon in Malmesbury 10 August 2005 - flow ~7.8 MI/d

## Restoring Sustainable Abstraction

### Environmental assessment in support of application to vary Wessex Water abstraction licences

Author	 Andy House (Wessex Water) Section 5.4	
Checker		
Approver		
Report No	UA000221-ARC-XX-XX-RP-ZA-0001-03	
Date	DECEMBER 2017	

### VERSION CONTROL

Version	Date	Author	Changes
01 Draft	5 June 2017		-
02	23 Oct 2017		-
03	18 Dec 2017		Minor changes to Table 17 and Figure 53

This report dated 18 December 2017 has been prepared for Wessex Water (the "Client") in accordance with the terms and conditions of appointment dated 16 September 2015 (the "Appointment") between the Client and Arcadis Consulting (UK) Limited ("Arcadis") for the purposes specified in the Appointment. For avoidance of doubt, no other person(s) may use or rely upon this report or its contents, and Arcadis accepts no responsibility for any such use or reliance thereon by any other third party.

## Executive Summary

The Malmesbury Avon upstream of Great Somerford drains a southern portion the Cotswolds. The river comprises two main tributaries, the Sherston Avon and Tetbury Avon, which confluence in Malmesbury forming an integral part of the town. During the dry summers of the early 1990's, the Sherston Avon dried in Malmesbury and the Tetbury Avon was reduced to a trickle. This drying was due to abstraction from groundwater for public water supply (PWS) and identified that licensed mitigation measures (stream support) were inadequate. This report details a solution to restore acceptable flows to the Malmesbury Avon.

The baseflow in the Malmesbury Avon is from the Great Oolite and Forest Marble aquifers, with runoff from mudstone and clay rich outcrop of other strata leading to the catchment's flashy nature. The Great Oolite aquifer is underlain by the Lower Fuller Earth, which separates it from the Inferior Oolite aquifer. The Inferior Oolite outcrops along the Cotswolds scarp edge and dips eastwards, becoming a confined aquifer beneath the Malmesbury Avon catchment. Geological faulting is present across the Malmesbury Avon catchment and fault displacement is sufficient for the juxtaposition of the two aquifers near Malmesbury, such that Inferior Oolite can drain to the Malmesbury Avon via the Great Oolite.

For decades the Great and Inferior Oolite aquifers have been used for PWS. Bristol Water operates three sources within the catchment, two which abstract from the Inferior Oolite (Long Newton and Tetbury) and one which is constructed to draw water from both aquifers (Shipton Moyne).

In the early 1970s Wessex Water predecessor' operated three sources in the vicinity of Malmesbury: Charlton, Park Road and Rodbourne. In the mid 1970s a major study was undertaken to increase PWS from these and new Great Oolite sources, with new sources constructed at Cowbridge and Milbourne. The study identified the need to mitigate the PWS impact on river flow at the proposed abstraction rates. In response stream support (SS) boreholes will drilled, with water from these added to streams to augment flows. Four SS boreholes abstract from the inferior Oolite and four from the Great Oolite. The resultant Malmesbury Groundwater Scheme was licensed in 1981. However, in 1990 even with full stream support occurring the river dried in Malmesbury.

Consequently, the National Rivers Authority (now the Environment Agency (EA)), Wessex Water and Bristol Water worked to together to improve river flow, with the signing of a Memorandum of Understanding. The solution to improve flows was to reduce PWS abstraction and use the freed-up resource for increased SS. Wessex Water's plan for increased SS from three of the Inferior Oolite sources (Luckington, Stanbridge and Tetbury) was also agreed in a subsequent Statement of Intent document. The Malmesbury Avon is an EA Restoring Sustainable Abstraction scheme.

Since 1999, Bristol Water have reduced licensed abstraction by ~10 MI/d, and have made a subsequent additional reduction of 1.5 MI/d. Since 1995, under 32(3) consent approval, Wessex Water have been trialling increased SS, to maintain new/revised target flows along the Malmesbury Avon. The target (amenity) flows were set following use of 'river diarists', who reported on the visual acceptability of the observed flow. Since 1995 these target flows have been maintained along the Malmesbury Avon, except for minor blips due to pump failures and in the summer of 2013.

Establishing the sustainability of this new SS arrangement has been the main focus of the work presented in this report. To determine this, the daily SS requirement needs to be known. Examination of the historic river flow and groundwater level has allowed the SS requirement from 1978 to 2015 to be calculated. The most demanding year was 1990, and separate analysis has shown that the SS need in 1990 was greater than in 1976. On average (1978-2015) the SS (combination of the three sources) requirement was 2.4 MI/d, though peak use was predicted to be 25 MI/d, with a maximum annual total of 3,742 MI (1990). This analysis includes an allowance for the extra SS requirement if the WW PWS sources had been operated at full licence, rather than at historic rates. A simple Great Oolite model was developed to define this extra need.

A numerical model of the Inferior Oolite and the underlying Bridport Sand has also been developed and calibrated to assess: 1) the sustainability of the proposed PWS and SS abstractions, 2) changes to the flow from natural outflow points e.g. scarp edge springs/streams and 3) impact upon protected rights.

Modelling shows no long term decline in Inferior Oolite water levels, i.e. no mining, with the long term abstraction rate not exceeding the long term recharge rate. The proposed PWS and SS arrangements do result in reductions in scarp slope stream flow, but the reductions are less than under the currently licensed arrangements. A detailed examination of empirical data has established that the proposed increased SS abstractions (active since 1995) do not impact flows along the By Brook, the neighbouring catchment to the south of the Malmesbury Avon catchment.

Modelling output has identified that under 1990 conditions the aquifer water level recesses to just above the 'derogation prevention level' (set 3m above the pump intake) for one protected right. Options to increase the margin of safety were explored. An options appraisal exercise concluded that, via an Inferior Oolite groundwater level control curve, BW will reduce abstraction by 1.5 MI/d at times of low groundwater. When the BW abstraction is restricted by the control curve this reduces BW's deployable output by 1.5 MI/d, therefore, Wessex Water will supply BW with 1.5 MI/d from the Cowbridge source, via a new pipeline (being constructed in 2017). Modelling has shown that application of this measure increased the margin of safety above the derogation prevention level by 2.5m.

The use of the control curve and provision of the pipeline transfer, also provides a mitigation measure if the SS need is actually higher than predicted.

A residual concern exists over the impact of the Cowbridge PWS source on the lower reach of the river from Malmesbury to Great Somerford. During, the trialling of increased SS (since 1995) the target flow at Great Somerford has been maintained, whilst flow at the upstream gauges have been maintained, in all years except in 2013. One differing factor in 2013, compared to previous years, was the higher rate use of Cowbridge PWS in 2013, which is the PWS source closest to the river. Trialling of the Cowbridge source, at different groundwater levels, to gauge its impact on the river flows was planned in subsequent years, but 'wet' summers e.g. 2014 and infrastructure constraints have meant the trials could not be undertaken in the conditions required. Consequently, to reflect the same operational PWS arrangement, when the Great Somerford prescribed flow was maintained in 'dry' years, e.g. 2011, WW propose to use Cowbridge as the source of 'last use' i.e. demand will be met from the other three sources ahead of Cowbridge. It is proposed that the use of Cowbridge is controlled by an Operating Agreement. The Operating Agreement will need to allow a small amount of regular use keep the supply main serviceable and to allow a transfer to BW if the Inferior Oolite aquifer water level is below the control curve.

Since 1995 neither Wessex Water or the EA have received complaints about the poor appearance of the river due to low flows, except for one letter to the EA in 2009, referring to the river downstream of the Sherston-Tetbury confluence in the Baskerville part of Malmesbury. Wessex Water requested more details about the complaint, location and date, but no further information was forthcoming.

Although primarily set to restore amenity flows to the Malmesbury Avon, ecology monitoring of the river has shown that the expected, macrophytes, macroinvertebrates and fish are present along the river. Analysis of the macroinvertebrate data does not show a low flow stress.

In summary, trialling and modelling, shows that the combination of PWS reductions by Bristol Water and Wessex Water and increased SS from three Wessex Water Inferior Oolite aquifer boreholes, restores sustainable abstraction and hence acceptable flows to the Malmesbury Avon, subject to an Operating Agreement controlling the use of Cowbridge.

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# 1 Summary of application and environmental assessment

## 1.1 Introduction

This report details the proposal to vary existing abstraction licences held by Wessex Water and an environmental assessment of the proposed variation. The licence variation seeks to make permanent changes to river augmentation, trialled for the last 20 years, and reduces licensed public water supply (PWS) abstraction, to achieve acceptable flows in the River Avon upstream of Great Somerford. This reach of the River Avon is known locally as the Malmesbury Avon. The Malmesbury Avon is located near the southern end of the Cotswolds, north of the M4 (Figure 1). The licence variations represent the culmination of 25 years of investigations, trials and investment to restore acceptable flows in the Malmesbury Avon. Bristol Water are making a corresponding licence change, which together will restore sustainable abstraction to the Malmesbury Avon catchment.

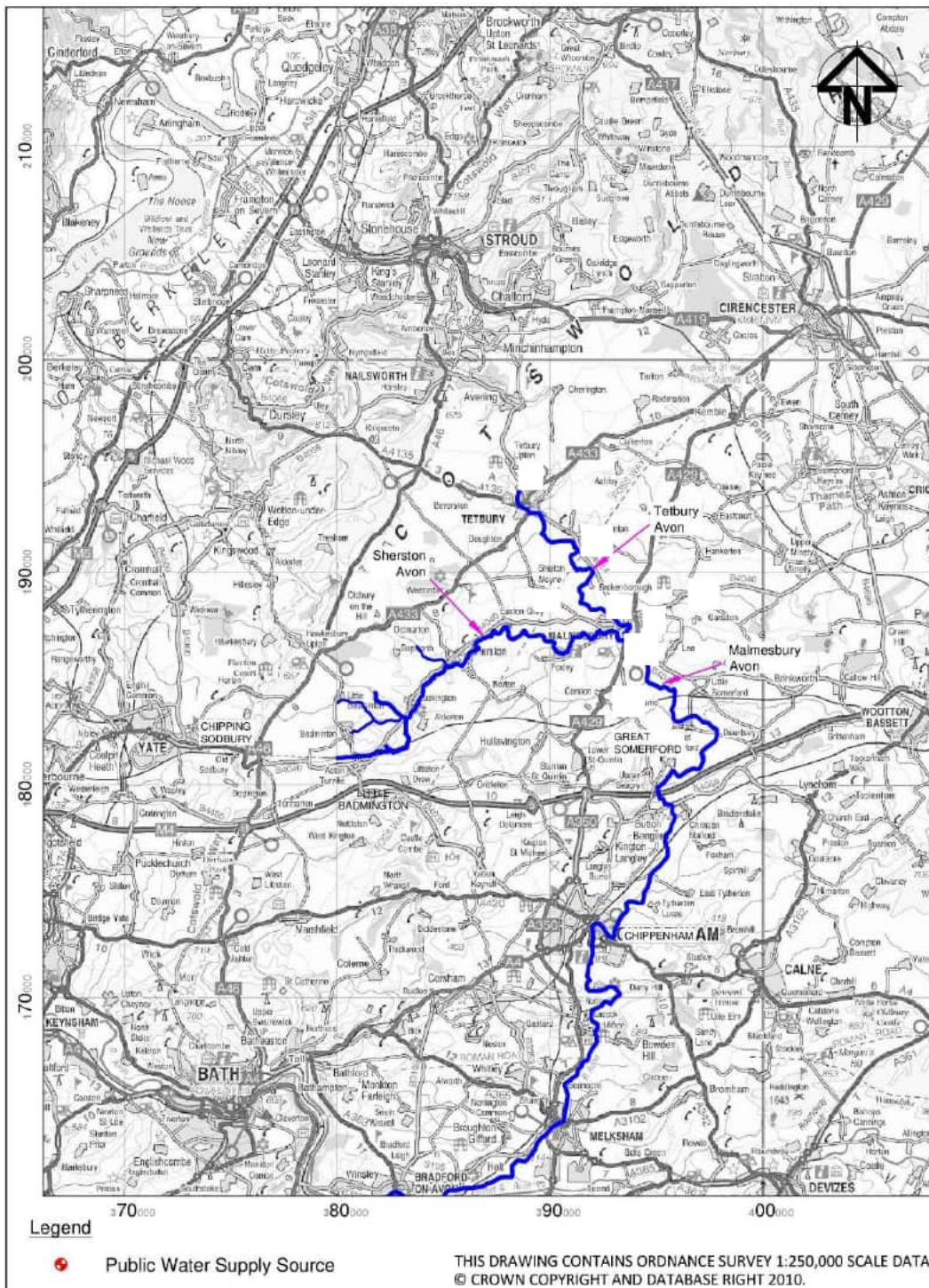


Figure 1 Location map showing Malmesbury Avon and public water supply sources

## 1.2 History of low flow and mitigation works

There are two principal aquifers beneath the Malmesbury Avon catchment: the Great Oolite and the deeper Inferior Oolite, separated by Fuller's Earth clay. These aquifers provide flow to the Malmesbury Avon, and are responsible for maintaining the river flow (base flow) during dry/drought periods. The aquifers have been pumped for PWS for over eight decades. Wessex Water and Bristol Water (BW) are licensed to operate eight PWS sources within the catchment. In addition, Wessex Water is licensed to operate eight sources for stream support (SS), to mitigate the PWS impact on river flows. The locations of these sources are shown on Figure 2. The aquifers are also used for private water supplies: mainly for domestic and agricultural use.

The 'Malmesbury Groundwater Scheme' (MGS, operated by Wessex Water) was licensed in 1981. This permitted new and increased abstraction from five Great Oolite PWS sources around Malmesbury: Charlton, Cowbridge, Milbourne, Park Road and Rodbourne. The licence also requires the use of four Inferior Oolite boreholes at Luckington, Tetbury, Stanbridge and Hullavington and four Great Oolite boreholes at Charlton, Cowbridge, Lower Stanton St Quintin, and Park Road as SS sources to try and maintain prescribed flows along the Malmesbury Avon down as far as upstream of Great Somerford.

Bristol Water operates three sources for PWS in the Malmesbury Avon Catchment: Long Newnton, Shipton Moyne and Tetbury. The sources at Long Newnton and Tetbury draw water from the Inferior Oolite. The source at Shipton Moyne is constructed to draw water from both the Great and Inferior Oolite aquifers. The Shipton Moyne source has been operational since the 1930s and Tetbury since the 1910s.

During the late 1980s and 1990s public concerns were raised regarding low flow in the Malmesbury Avon and its tributaries. In 1992, the National River Authority (Environment Agency's predecessor) commissioned WS Atkins to investigate the cause of the low flow and to recommend actions to ameliorate the situation. To investigate the causes of low flow WS Atkins developed a detailed hydrological/hydrogeological flow model (MIKE-SHE software) for the Malmesbury Avon catchment.

In September 1994 WS Atkins reported on the findings of the modelling work (WS Atkins, 1994). It was concluded in the report that abstractions by Wessex Water and Bristol Water were reducing the river flow to a rate which was at times environmentally unacceptable. The impact has at times been exacerbated by low rainfall e.g. 1995, when only a trickle of flow was present in the Sherston Avon at Malmesbury (Figure 3). The low river flows in 1995 confirmed that the existing licence conditions were inadequate to protect flows along the Malmesbury Avon.

The WS Atkins report presented several options to improve river flow. Following detailed discussions between the Environment Agency, Wessex Water and Bristol Water, a Memorandum of Understanding (MoU) was agreed in 1996 (Appendix A). The memorandum set out what each of the parties would do to reach a permanent solution, the Water Companies agreed to:

**Wessex Water:** to investigate increasing stream support abstraction from three of the Inferior Oolite SS sources (Luckington, Stanbridge and Tetbury) and investigate the potential for change to the PWS abstraction regime which is less damaging.

**Bristol Water:** Reduce the abstraction from Shipton Moyne. Bristol Water stopped using Shipton Moyne in December 1998. The shortfall in supply was provided by the Purton Source which takes water from the Severn Canal.

Trials by Wessex Water to investigate the benefit of the MoU strategy commenced in 1995. This involved pumping the Luckington, Stanbridge and Tetbury SS boreholes up to 10 Ml/d, when required. The 1981 licence permitted a maximum abstraction of 2.5 Ml/d from each of these stream support boreholes.

In 1999, the Environment Agency published the 'National Environment Programme' (NEP, Environment Agency, 1999). The NEP identified low flow problems nationwide. The Malmesbury Avon was listed by the Environment Agency as a 'Restoring Sustainable Abstraction' scheme, and proposed the cessation of abstraction from Cowbridge as a remedial measure.

Wessex Water proposed improving its network to allow water from an existing source at Blashford Lakes, near Ringwood, to address the concern in the NEP. Once this was implemented water from the Blashford source would have allowed the Cowbridge source to be taken out of supply. The Blashford source would also have allowed two other environmentally sensitive sources (listed in the NEP) in other parts of the Wessex Region to be switched off: Alton Pancras (River Piddle) and Chitterne (River Wylfe). Funding to implement the Blashford scheme was requested under the Wessex Water's AMP3 submission. However, the Water Services Regulation Authority (Ofwat) considered that the scheme did not provide 'good value for money'.

Restoring Sustainable Abstraction – Malmesbury Avon

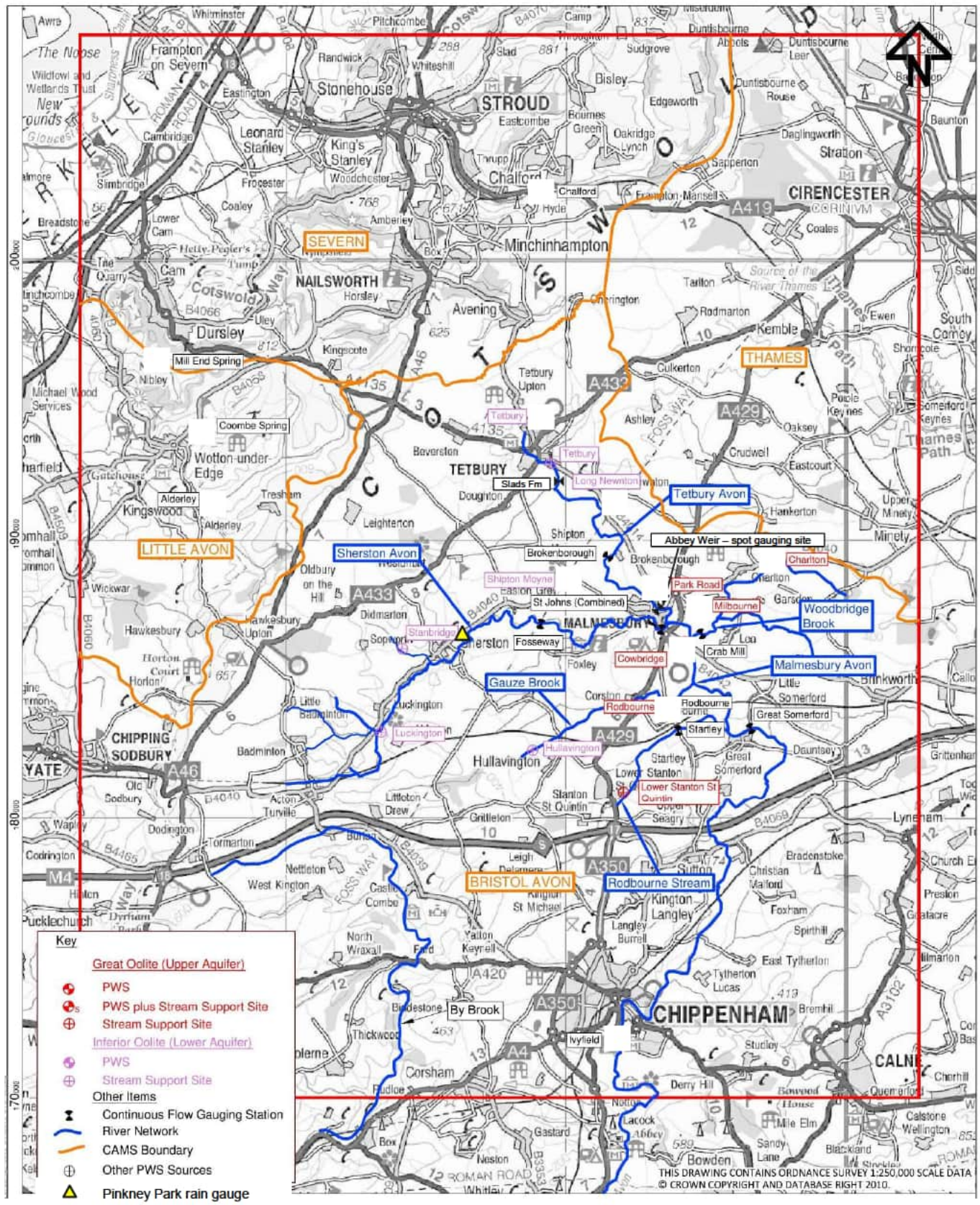


Figure 2 Location map of river network and key features

SHERSTON AVON AT ST JOHNS BRIDGE, MALMESBURY



12 JULY 1995 : FLOW <1 ML/d

TETBURY AVON AT ABBEY WEIR, MALMESBURY



19 AUGUST 1995 : FLOW <3.7 ML/d



10 AUGUST 2005 : FLOW ~7.8 ML/d



22 SEPTEMBER 2005 : FLOW ~6.8 ML/d

Figure 3 Visual appearance of Malmesbury Avon in 1995 and 2005

Following this decision, Wessex Water worked with the Environment Agency, Ofwat and English Nature (now Natural England) in relation to Chitterne PWS to develop a local solution to the low flow problems. In relation to the Malmesbury Avon a 'proposed scheme' was formulated, which comprised:

- Restricting the abstraction from Cowbridge PWS
- Increasing the SS abstraction from three Inferior Oolite boreholes.

Wessex Water signed a **Statement of Intent (Sol)** in June 2002 with the Environment Agency, Ofwat and English Nature to investigate the viability of the proposed scheme (plus similar schemes for the River Piddle and River Wylye) and, if successful, to submit a licence application. If the scheme is unsuccessful then Wessex Water would work with the signatories of the Sol to investigate other solutions. This licence variation seeks to formalise the findings of the Sol work.

### 1.3 Statement of Intent (2002 to March 2007)

A copy of the Statement of Intent is contained in Appendix B. A steering group comprising representatives from Defra, Ofwat, Environment Agency, English Nature and Wessex Water was formed to oversee the project and to provide guidance.

The implementation of the Sol was specified in an **Operating Agreement (OA)**, under Section 20 of the Water Resources Act 1991, between the Environment Agency and Wessex Water. A copy of the OA is contained in Appendix C. The sections of the OA pertinent to the Malmesbury Avon are outlined below.

#### 1.3.1 Use of Cowbridge

Cowbridge was the last PWS source to start abstraction in the catchment, commencing in 1984. Consequently, when low flows occurred in the early 1990s Cowbridge was viewed as the main cause. Hence the Sol OA sought to restrict the abstraction from Cowbridge.

The rules set in the OA are designed to ensure that full use was being made of the other sources of water available to Wessex Water, including a bulk transfer from Bristol Water, before abstractions were made from Cowbridge, Alton Pancras and Chitterne. Use of the Cowbridge source under the OA was permitted under any one of the following conditions:

- If the flow at Great Somerford gauging station is greater than or equal to 103.7 MI/d (1.2 m<sup>3</sup>/sec) over the preceding seven days, up to 5 MI/d may be abstracted. If the flow at Great Somerford gauging station is greater than or equal to 155.5 MI/d (1.8 m<sup>3</sup>/sec) over the preceding seven days, up to 7.5 MI/d may be abstracted. However, if the flow is above these levels and stream support is in use on either the Tetbury Avon or Sherston Avon then there will be no abstraction.
- When there is an operational emergency when up to 7.5 MI/d may be abstracted.
- When more than 10 MI/d is being imported from Bristol Water.

#### 1.3.2 Revised trigger/target river flows

As detailed above, the existing licence conditions are inadequate to protect flows along the whole of the Malmesbury Avon, upstream of Great Somerford. To address this, new and revised flow trigger/targets were set along the Avon. These flow targets were devised by the Environment Agency as an 'acceptable flow' that would ensure adequate amenity flows in Malmesbury and a healthy river ecology. A trigger flow starts the upstream stream support when the river flow recesses below the trigger flow. A detailed description of the revised flow triggers/targets is provided in Section 2.5. Ecological monitoring, specified in the OA, has been undertaken to assess whether the target flows are adequate to achieve a 'healthy' river ecology; the findings are presented in Section 5.4.

#### 1.3.3 Increased stream support

Under the OA, increased SS abstractions are permitted (by Section 32(3) Consents) from three Inferior Oolite sources. Abstraction rates were increased from 2.5 MI/d to 10 MI/d from each source. A detailed description of the historical use of each source is given in Section 2.6. Stream support discharge rates have been set to ensure the revised target flows are maintained. At certain times in 2003 ('signal test') and 2004 more stream support has been discharged than required, as part of trial pumping to improve understanding of the aquifer behaviour.

### 1.3.4 Public Consultation

The main reason to improve river flows was the complaints received from the public about the appearance of the river, especially through Malmesbury, in the late 1980s and early to mid-1990s. Consequently, the public were asked to be involved in determining what level of flow yielded an acceptable appearance. This work was done by a group of volunteers who became known as the 'river diarists', who regularly inspected the river and recorded their opinions. The results of this work were used to set new river flow targets.

In 1995, Wessex Water held several exhibitions in the catchment and issued press releases to explain the works being undertaken to improve river flow, namely increased Inferior Oolite stream support.

Since 1995 and during the Sol period of investigation, the Environment Agency/Wessex Water/Bristol Water have issued at regular intervals (spring/summer/autumn) a 'Malmesbury Bulletin', detailing the river flow, abstraction rates and testing being undertaken. A copy of one bulletin from October 2003 is contained in Appendix D. The bulletin was circulated to stakeholders in the catchment and a list of the recipients is contained in Appendix D.

As part of the Sol work a public consultation group was set up to disseminate information and to allow local opinions on the 'success' of the solution to be collected. The consultation group met twice a year (winter and summer); with the summer meeting held in the catchments to allow inspection of the rivers. Since 2006 meetings have not been held, with parties kept informed of progress via the annual report.

The findings from the Sol work were presented to a public meeting in Malmesbury, hosted by the Malmesbury River Valleys Trust, in June 2006.

### 1.3.5 Annual report

The OA required the preparation of an annual report that described work in the previous calendar year, including:

- Climatic conditions, the public water demand, groundwater level conditions and the flow status of the rivers;
- Usage of the Sol PWS sources;
- Operation of the SS sources and the benefits this has brought to river flows;
- The environmental monitoring programme undertaken;
- Other relevant works undertaken;
- An outline of how the sources will be operated during the forthcoming year;

During the period of the Sol, five annual reports were prepared (Wessex Water 2003; 2004a; 2005; 2006; 2007a). The annual reports were submitted to the relevant Minister within Defra, and any feedback comments were circulated to the steering group and public consultation group.

### 1.3.6 Review Report and Conclusions

The Sol required a review of the effectiveness of the 'solution', this was completed in May 2007 – Review Report (Wessex Water, 2007b). Regarding the Malmesbury Avon catchment, the Review Report concluded that a combination of reducing annual PWS abstraction (from the Great Oolite sources) and increasing SS (from the Inferior Oolite aquifer) had restored acceptable flows, which were both sustainable and gave a healthy river ecology. The evidence to support this conclusion is presented subsequently in this document.

A similar conclusion was drawn from the studies undertaken on the Upper Piddle and Chitterne Brook. However, works regarding the impact on the Chitterne source, in particular on the River Till were on-going and hence a firm conclusion could not be drawn.

During the Sol period, if the 'solution' was deemed effective then a licence application should be submitted to formalise the arrangement. However, with the impact of the Chitterne source unresolved, it was decided to delay any licence matters until the Chitterne PWS impact was known. In addition, these potential licence changes were potentially influenced by other factors such as a variation to Wessex Water's Wimbleball licence and consequently all signatories to the Sol agreed to an extension of the Sol period; a **Revised Statement of Intent (RSol)** was duly signed.

## 1.4 Revised Statement of Intent (2007 to 2010)

The RSol covers the period May 2007 to March 2010, a copy of the document is contained in Appendix E. During this period, the sources (PWS & SS) were to be used as set out in the Review Report. This operating procedure was formalised by a revised OA, a copy of which is contained in Appendix F. The sections of the revised OA pertinent to the Malmesbury Avon are outlined below.

### 1.4.1 Use of PWS sources

The restoration of river flow through Malmesbury is principally due to the increased discharge of stream support water. The abstraction reduction at Cowbridge only delayed the need for stream support by a few days (Section 3.4.3). Consequently, during the RSol period the constraints on the use of Cowbridge in the 2002-2007 Sol were removed and no specific restriction on the use of Cowbridge has been imposed. Rather, the annual abstraction total from the PWS sources has been reduced from 14,540 MI to 12,775 MI (abstracting from Charlton, Cowbridge, Milbourne and Rodbourne. Park Road PWS usage has been reduced to zero).

Charlton and Milbourne are to be operated in accordance with their current licence source conditions, Rodbourne to be operated in accordance with its current licence source conditions but daily abstraction restricted to a maximum of 13.0 MI/d. Further details can be found in Appendix E.

### 1.4.2 Trigger and target river flows

All trigger and target flows on the Malmesbury Avon remain the same as in the original OA, except for Brokenborough, this trigger/target flow has been lowered from 8.0 MI/d to 6.8 MI/d. The original value was set 'high' to allow for leakage downstream of Brokenborough along the Tetbury Avon prior to Abbey Weir, which has a flow target of 6.8 MI/d. Monitoring during the Sol period did not identify any leakage and hence the trigger/target flow at Brokenborough was lowered. No complaints regarding the appearance of the river flow in the Tetbury Avon have been received whilst flows have been maintained at 6.8 MI/d.

### 1.4.3 Increased SS

During the RSol period, higher rates of Inferior Oolite SS abstraction are permitted (up to 10 MI/d from each borehole – Luckington, Stanbridge, Tetbury) to ensure target flows are maintained.

### 1.4.4 Reporting

The RSol requires the production of an Annual Report, based on a 'licence year' (April - March); two reports have been prepared: a sixth and seventh annual report (Wessex Water, 2008; 2009).

The findings of the RSol work and implementation were documented in a second review report (Wessex Water, 2010). The RSol work confirmed the Sol findings and Wessex Water planned to submit a licence application, with a concurrent Bristol Water licence change related to Shipton Moyne.

## 1.5 2010 to 2016 work

In 2010, a draft environmental assessment report, in support of a licence application to implement the SOI findings (Hyder Consulting<sup>1</sup>, 2010) was submitted to the Environment Agency for consideration. Feedback from the Environment Agency expressed concern about the low groundwater level reached in the Inferior Oolite aquifer if there were to be a repeat of the very dry 1990 summer/autumn, and whether the margin of safety regarding private water supplies was adequate. In response, the modelling assessment approach of the Inferior Oolite aquifer was amended. The results from this modelling work showed that in a repeat of 1990 conditions, derogation of private water supplies could occur. Consequently, a period of consultation with Bristol Water and Environment Agency, and model runs were undertaken to find a sustainable solution (Section 4). The outcome of this is:

- Bristol Water to reduce abstraction by a further 1.5 MI/d, to a new annual limit of 3573 MI from Tetbury, Shipton Moyne and Long Newnton, equivalent to a daily average of 9.79 MI/d.
- Use of a groundwater control curve to further reduce Bristol Water abstraction by 1.5 MI/d. When this occurs, Wessex Water will transfer 1.5 MI/d from the Cowbridge source to the Bristol Water network to make up the shortfall.

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<sup>1</sup> Now Arcadis Consulting (UK) Ltd

During this period, the PWS and SS sources continued to operate under the terms of the RSol, the extra SS rates authorised by Section 32(3) consents. Acceptable river flows through Malmesbury were duly maintained.

Flows above the prescribed flow (pf) at Great Somerford have also been maintained, except in August and September 2013. Analysis of gauged tributary flows, upstream of Great Somerford, shows that in August/September 2013 a loss of river flow occurred along the river reach from Malmesbury to Great Somerford. This behaviour is at variance with all other years, when similar analysis shows a gain along this reach. This issue is described and examined in more detail in Section 3.3.7. One differing factor in 2013, compared to other years, was the higher rate use of Cowbridge PWS in 2013, which is the PWS source closest to the river. To identify if Cowbridge does change the flow behaviour along this reach testing was proposed. The testing was designed to alter the Cowbridge abstraction rate, with concurrent changes at the other sources. However, a combination of 'wet' summers e.g. 2014, and operational issues has meant trialling at times of 'low' groundwater levels could not be undertaken. Consequently, uncertainty remains over the impact of Cowbridge on this lower reach. Therefore, Wessex Water proposes to alter the pumping arrangement from the PWS sources that comprise the Malmesbury Groundwater Scheme. Via an Operating Agreement, Cowbridge will be set as the 'last source to run' this will limit its uses. In the coming summers trialling will be undertaken to establish the impact of Cowbridge on river flows, and the operating agreement/licence amended to reflect the findings.

## 1.6 Environmental benefits of MoU and (R)Sol solution

The overall conclusion from the assessment work, detailed subsequently in this report, is that:

- The implementation of the MoU by Bristol Water and additional changes detailed in Section 1.5 (reducing licensed quantity) and variation to Wessex Water licences will allow acceptable (target) river flows to be maintained along the Malmesbury Avon, even in a very dry year.
- Environmental monitoring during the trialling of this solution, for the last 20 years, has shown that the augmented river flows ensure a good river water quality and a healthy river ecology: the expected type and abundance of macroinvertebrates, macrophytes and fish are present for this type of river.
- The principle factor in improving river flows is the increased use of stream support abstractions from the Inferior Oolite aquifer. Analysis has identified that the Inferior Oolite aquifer has adequate and sustainable groundwater resources available to meet the stream support demand.
- The improvement in the river's appearance as a result of these changes can be seen on Figure 3, which shows the river in 1995 suffering low or no flow, and in 2005 with the flows at or just above to the target rates.

### 1.6.1 Summary of licence application

Based on the environmental benefit assessment, proposed variations to two Wessex Water licences are detailed in this report that will result in acceptable river flows being maintained along the Malmesbury Avon and sustainable abstraction restored. The proposed variations involve a reduction in Wessex Water PWS abstraction and increased stream support abstraction from the Inferior Oolite aquifer, and a concurrent reduction in the Bristol Water PWS abstraction. Overall there is net reduction in abstraction from the Inferior Oolite aquifer. These changes have effectively been trialled since 1999. The proposed Wessex Water licence changes are detailed in Section 6, a summary is provided in Table 1 comparing the existing and proposed abstraction rates for PWS and SS.

Table 1 Summary of Wessex Water licence variations

Use	Current Licences (MI)	Proposed Licences (MI)
PWS		
Daily	47.5 (winter) 41.1* (summer)	39.1
Annual	14,540 (39.8 MI/d)**	12,775 (35 MI/d)**
SS - Daily		
Great Oolite	17.5	5
Inferior Oolite	10	27.5

\* 39.1 MI/d when SS are maximised. \*\* Annual quantity expressed as a daily average

## 1.7 Report structure

Section 2 describes the Malmesbury Avon catchment, geological setting and hydrological setting. The historical and current usage of public water supply and stream support sources within the catchment are also described.

Section 3 looks at the impact of the PWS abstractions on river flow and details the amount of stream support water required to maintain the target flows along the Malmesbury Avon, based on proposed full licence use of the PWS sources.

The licence variation involves an overall reduction in the level of abstraction from the Inferior Oolite in the long term, but during dry years daily abstractions rates may exceed historic levels. In Section 4, the development of a calibrated numerical model of the Inferior Oolite (and Bridport) Sand) is described. Model output is used to assess the sustainability of the proposed abstraction regime and impact on watercourses and protected rights.

Flow targets specified in the revised OA will be incorporated into the revised licence. These flow targets have been maintained since 1995. Environmental data collected during the period of investigation allows the suitability of the target flows to be assessed. This assessment is contained in Section 5 where water quality (chemistry), ecology (macro invertebrates and macrophytes), visual appearance and fishery status of the river are examined to show that the proposed licence variation provides a healthy environment.

Section 6 of the report details the proposed variations to the Wessex Water licences.

The conclusions of the report are presented in Section 7.

## 2 Study area

### 2.1 Introduction

Key features of the Malmesbury Avon catchment and surrounding area are described in this section. Surrounding areas are included as the groundwater catchment supplying the source boreholes extends beyond the Malmesbury Avon surface water catchment area. In addition, water features potentially at risk from increased SS abstraction are located outside the Malmesbury Avon surface water catchment area, e.g. the By Brook. A study area has been set to encompass the area of potential impact (shown as a red box on Figure 2).

### 2.2 River network and topography

The overall objective since 1990 has been to restore acceptable flows in the River Avon upstream of Great Somerford. The surface water catchment boundary and river network upstream of Great Somerford are shown on Figure 2. The river upstream of Great Somerford is locally called the Malmesbury Avon; this definition will be used throughout the remainder of the report. At Malmesbury the river divides into two upstream branches, a northern branch, referred to as the Tetbury Avon, and a western branch, referred to as the Sherston Avon (Figure 2).

The surface water catchment area of the Malmesbury Avon upstream of Great Somerford is ~303 km<sup>2</sup>. The outcrop geology within the catchment is predominantly limestones and clays and this geology strongly influences the river flow hydrograph. The topography of the area is dominated by the Cotswolds scarp and dip slopes, formed from relatively resistant limestone strata. The scarp slope forms the main feature along the west margin of the study area. This area of high ground (~200 mAOD) leads to orographic rainfall. From the scarp ridge the topography dips gently eastwards, forming the Cotswold plateau. Rivers draining the plateau have in places (e.g. at Pinkney on the Sherston Avon) cut steeply sided valleys into the plateau. The main land use in the catchment is agriculture (grassland and arable). Settlements in the catchment are typically scattered hamlets and villages, with Malmesbury and Tetbury forming the main urban settlements.

The scarp area contains numerous springs and streams draining the Oolites and underlying Bridport Sand which flow westwards, as part of the Little Avon catchment, and north to the River Frome. The watercourses in the northeast of the study area drain east into the Thames catchment. To the south, the By Brook drains a large part of the study area.

### 2.3 Geology, hydrogeology and aquifer units

The Jurassic strata within the study area, which include the Great and Inferior Oolite, comprise an alternating sequence of limestones, mudstones and sandstones. From the edge of the Cotswolds escarpment, the strata are inclined southeast and attain a thickness of more than 200 m beneath Malmesbury, about 20 km down dip (British Geological Survey, 2000).

The generalised stratigraphy, lithology and thickness range of the principal mapped units are divided into two districts; the northern district (around Tetbury) and the southern district (south of the Malmesbury fault). The geology for each district and the aquifer status is detailed in Table 2 (British Geological Survey, 2000). A simplified outcrop geology map is shown on Figure 4.

Table 2 Geological sequence and aquifer status

Group/ Formation	Member	Lithology	Thickness (m)		Aquifer Status	
			N	S		
Oxford Clay		Mudstone		>25	Unproductive	
Kellaways		Mudstone, sandy		24	Unproductive- Secondary	
Cornbrash		Limestone, shelly and sandy.	1-2	8	Secondary	
Forest Marble	Undivided	Mudstone, shelly with lenticular sandstone, ooidal and shelly limestone.	0-12	17-20	Secondary	
Upper Aquifer	Acton Turville	Limestone, shelly ooidal.	7-14	3-10	Principal	
	Chalfield Oolite (previously and more commonly known as the Great Oolite)	Bath Oolite, Twinhoe and Combe Down Oolite.	Limestone, ooidal	0-5	6-12	Principal
	Fuller's Earth	Upper Lansdown Clay	Mudstone, Silty		0-10	Secondary
		Athelstan Oolite	Limestone, ooidal	10	13	
		Tresham Rock	Limestone, shelly	10	3	
		Hawkesbury Clay*	Mudstone, calcareous	4-11*		
Taynton Stone & Cross Hands Rock	Limestone, shelly, part fine grained	3-5	3-9			
Lower Fuller's Earth		Mudstone, calcareous	27	10-20	Unproductive	
Lower Aquifer	Inferior Oolite	Limestone, ooidal, shelly	41-46	10-20	Principal	
	Bridport Sand **	Sandstone poorly cemented	60	46	Secondary	
Downcliff Clay/ Dyrham Silt		Mudstone, silty with thin muddy limestone.	>5	>5	Unproductive	

\* Not included with Upper Aquifer in the southern area. \*\* Previously known as Cotteswold Sand and Midford Sand

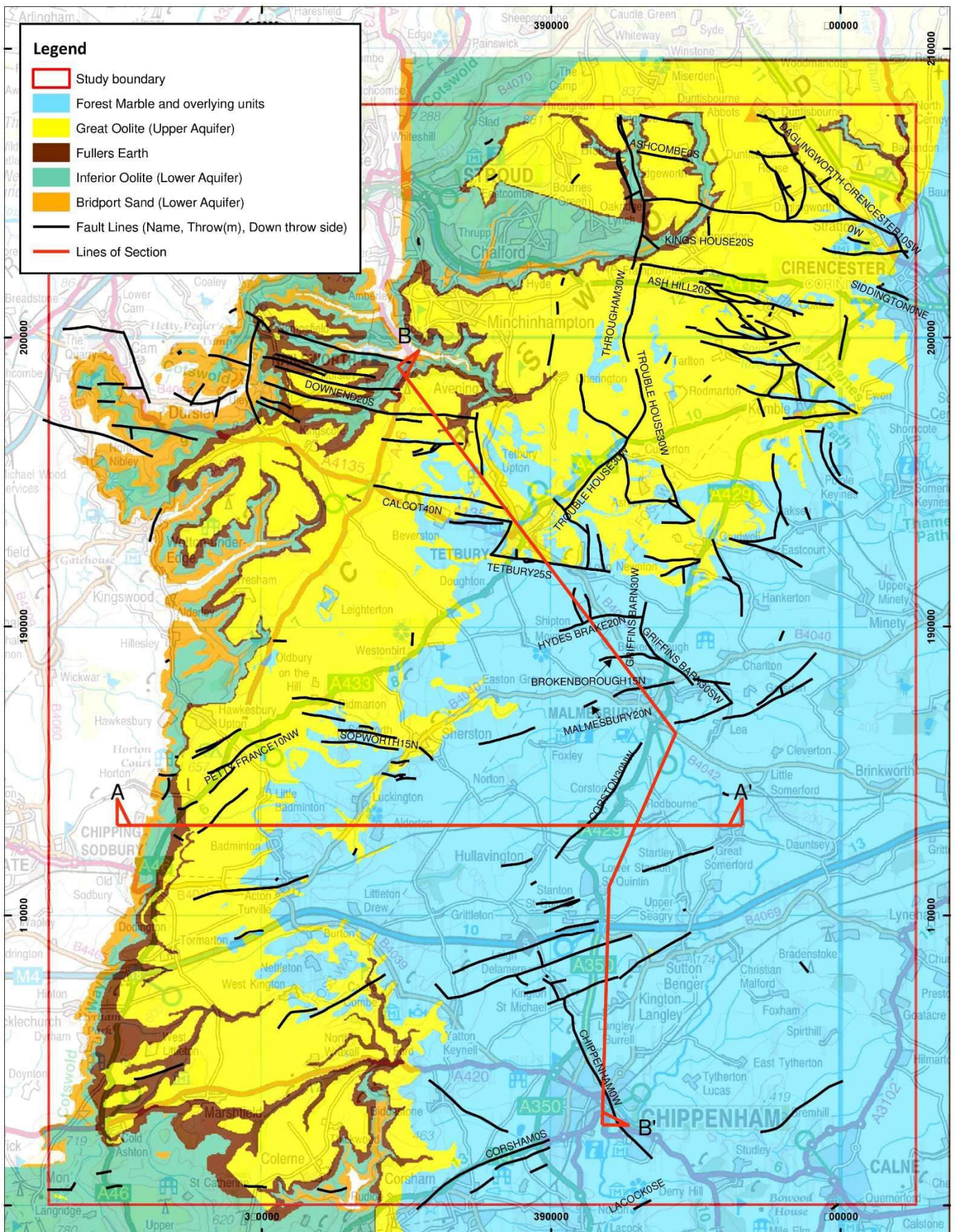


Figure 4 Outcrop geology and location of mapped faults

One of the principal characteristics of the Jurassic sequence around Malmesbury is the variability of lithology and thickness; both vertically and horizontally across the catchment. Several of the mapped subdivisions pass from one rock type to another.

As part of this work the British Geological Survey (BGS) were commissioned to construct a 3D geological model of the Inferior Oolite, Bridport Sand and Great Oolite aquifers. This has provided an important insight to the significance of fault throws and provided the aquifer geometry information for the numerical modelling (Section 4.2).

Two geological cross-sections through the study area are shown on Figure 5. The lines of section are shown on Figure 4. Figure 5a is a west-east section, following the regional geological dip. The other section (Figure 5b) is north-south along the general strike of the strata.

There are two main aquifers within the Jurassic strata. The Lower Aquifer comprises the Inferior Oolite together with the hydraulically connected underlying Bridport Sand Formation. Both strata have only a narrow outcrop at the edge of the Cotswold escarpment, and occur at depth throughout the catchment. The Upper Aquifer comprises the upper part of the Fuller's Earth, the Great Oolite and the lower part of the Forest Marble. These strata have a much wider outcrop, particularly in the north and west of the catchment. In the remainder of this report 'Great Oolite aquifer' also refers to the Upper Aquifer. In the remainder of the report the components of the Lower Aquifer are sometimes referred to separately.

The geometry of the aquifers means the outcrop, and hence recharge areas, are in the west. The aquifer strata dips eastwards, becoming confined by overlying clay rich horizons. Outflow from the aquifers occurs along the scarp edge and upstream of the confining edge of the Upper Aquifer, plus a down-dip exit route is also considered to be present for both aquifers.

Groundwater level monitoring shows a gradient eastward (down dip) towards Malmesbury in both aquifers. The ability to abstract water from the confined Upper Aquifer at rate suitable for PWS, indicates a down-dip flow direction along which permeability has been enhanced. The water abstracted for PWS only needs chlorination before entering the supply network. East of Malmesbury the yield from Great Oolite boreholes is poor and water quality deteriorates (increase salinity) (Bromley 1975). These above observations provide evidence for an exit route for the confined Upper Aquifer near Malmesbury. Similar evidence indicates a down-dip exit route for the inferior Oolite aquifer again near Malmesbury (Appendix G).

Within the study area there are more than 50 mapped faults at surface. Several unmapped faults are suspected (Section 4.5.3, BGS Mapping). Faults with 20 m or more displacement could juxtapose the Great and Inferior Oolite aquifers, allowing direct subsurface groundwater exchange. Large faults occur around Malmesbury which, together with the thinning of the Lower Fuller's Earth, allows horizontal and possibly vertical linkage between the aquifers (British Geological Survey, 2000) and disconnection of the Inferior Oolite into discrete blocks. The presence of hydraulically discrete Inferior Oolite aquifer compartments is described in Section 4.2. Groundwater flow along faults provides a route for the confined water in the Great Oolite and Inferior Oolite to leave the aquifer and enter the river in and near Malmesbury.

A fuller account of the study area geology is given in Appendix G (Inferior Oolite conceptual Model/Numerical Model Report).

Restoring Sustainable Abstraction – Malmesbury Avon

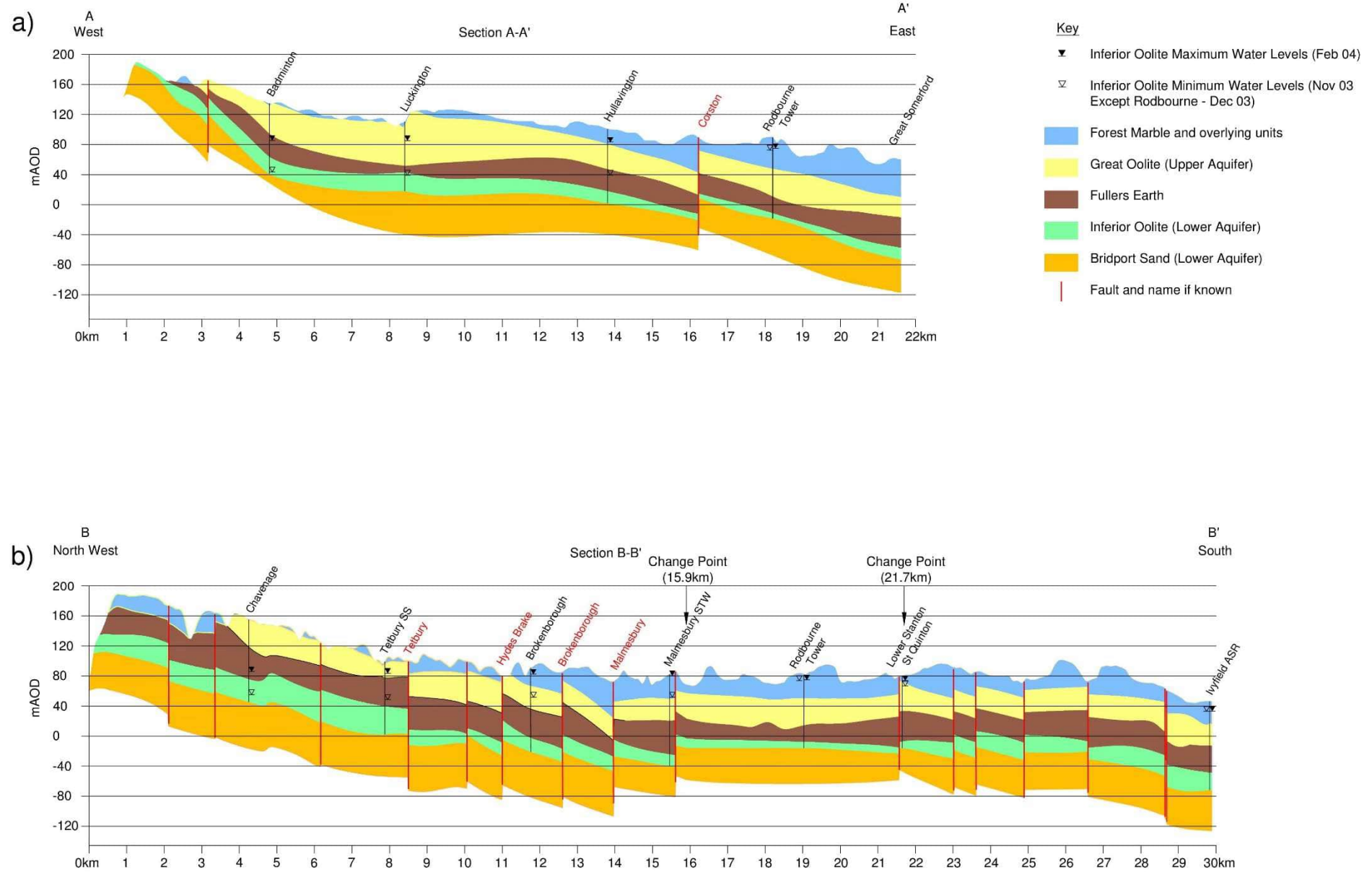


Figure 5 Geological cross-sections (A-A' & B-B') and Inferior Oolite water levels

## 2.4 Aquifer properties

The transmissivity and storage coefficient values obtained from literature and catchment-specific testing are summarised in Table 3.

Table 3 Summary of aquifer properties

Formation	Transmissivity (m <sup>2</sup> /d)	Storativity (confined)	Specific yield (unconfined)
Literature values			
Great Oolite	4 to 5900	6x10 <sup>-5</sup> to 4x10 <sup>-3</sup>	
Inferior Oolite	139 <sup>i</sup>	7x10 <sup>-5</sup>	8x10 <sup>-2</sup>
Bridport Sand	45 <sup>i</sup>		
Great Oolite	4 to 5900	6x10 <sup>-5</sup> to 4x10 <sup>-3</sup>	
Catchment specific			
Great Oolite	664 to 6854	7.6x10 <sup>-4</sup> to 3.63x10 <sup>-3</sup>	
Inferior Oolite	56 to 1600	0.7x10 <sup>-6</sup> to 2.3x10 <sup>-5</sup>	
Bridport Sand	6 <sup>ii</sup>		

<sup>i</sup>geometric mean

<sup>ii</sup>core sample; estimated aquifer thickness of 50m

The catchment-specific aquifer properties for the Great Oolite Aquifer have been taken from the results of pumping tests undertaken by Wessex Water at their PWS production boreholes at Cowbridge, Rodbourne, Park Road, Milbourne and Charlton (Wessex Water 1980). A fuller account of Inferior Oolite and Bridport Sand aquifer properties can be found in Appendix G.

## 2.5 Monitoring sites and target flows

### 2.5.1 Groundwater

Groundwater levels for both the Great Oolite and Inferior Oolite have been collected from an extensive monitoring network set up across the area. Some of the boreholes, for both aquifers, have been monitored by the Environment Agency since the 1970s providing good long term groundwater records. The locations of all the monitoring boreholes/wells are shown on Figure 6.

A fuller account of the monitoring network can be found in Appendix G.

### 2.5.2 River flow

The location of permanent flow gauging stations along the Malmesbury Avon and its tributaries are shown on Figure 2. In addition to the permanent Environment Agency gauging stations, numerous spot gaugings have been taken within the study area to augment the hydrological understanding. An examination of the hydrology of the Malmesbury Avon, particularly at times of low flow is given in Section 3.3.

#### Prescribed flows and Target flows

The current Malmesbury Groundwater Scheme licence specifies prescribed flows at three locations along the main river: Fosseway (Sherston Avon), Brokenborough (Tetbury Avon) and Great Somerford (Malmesbury Avon). Stream support abstractions are to be used to maintain the prescribed flows up to a maximum abstraction rate. Under the terms of the licence river flow can 'naturally' recess below the prescribed flow provided all stream support abstractions are at maximum licensed output (26 Ml/d).

As mentioned in Section 1.2, the current prescribed flow conditions on the MGS licence are inadequate to maintain acceptable flows along the whole of the Malmesbury Avon, as seen in June 1995 with no flow in the Sherston Avon through Malmesbury and a very low flow in the Tetbury Avon (Abbey Weir) (Figure 3).

To address this inadequacy the Sol OA and RSOI OA specifies new and revised trigger and target flows along the Malmesbury Avon. The trigger and target flow locations are listed in Table 4 and shown on Figure 2. Table 4 also details which source borehole provides the support water.

In 2016 the Environment Agency re-rated the Great Somerford flow structure, which effectively lowered flows below ~104 MI/d compared to the previous rating. The current prescribed flow of 28 MI/d equates to a flow of 26.6 MI/d under the new rating, so 26.6 MI/d has been adopted in this assessment and proposed licence variation as the Great Somerford prescribed flow.

River flows recess to the trigger flows in the Tetbury and Sherston Avon, ahead of the recession at Great Somerford. Therefore, the target flows on the Tetbury and Sherston Avon control the amount of stream support abstraction from the sources at Luckington, Stanbridge and Tetbury.

Table 4 Malmesbury Avon – Prescribed/Trigger/Target Flows

Gauging Point	Current licence prescribed flow (MI/d)	Trigger/Target	Flow (MI/d)	SS Action (under OA)
<b>SHERSTON AVON</b>				
Fosseway	8	Trigger	14	SS to commence at Luckington or Stanbridge
St John’s combined	-	Trigger/Target	7.2	SS to commence at Luckington or Stanbridge. Combined maximum abstraction of 20MI/d to maintain target flow
<b>TETBURY AVON</b>				
Brokenborough	6.5	Trigger/Target	6.8	SS to commence at Tetbury. Maximum abstraction of 10MI/d to maintain target flow
Abbey Weir	-	Trigger/Target	6.8	SS to commence at Tetbury. Maximum abstraction of 10MI/d to maintain target flow
<b>MALMESBURY AVON</b>				
Great Somerford	28	Trigger/Target	26.6 <sup>1</sup>	Stream Support to commence. Maximum abstraction of 37.5 MI/d to maintain target flow

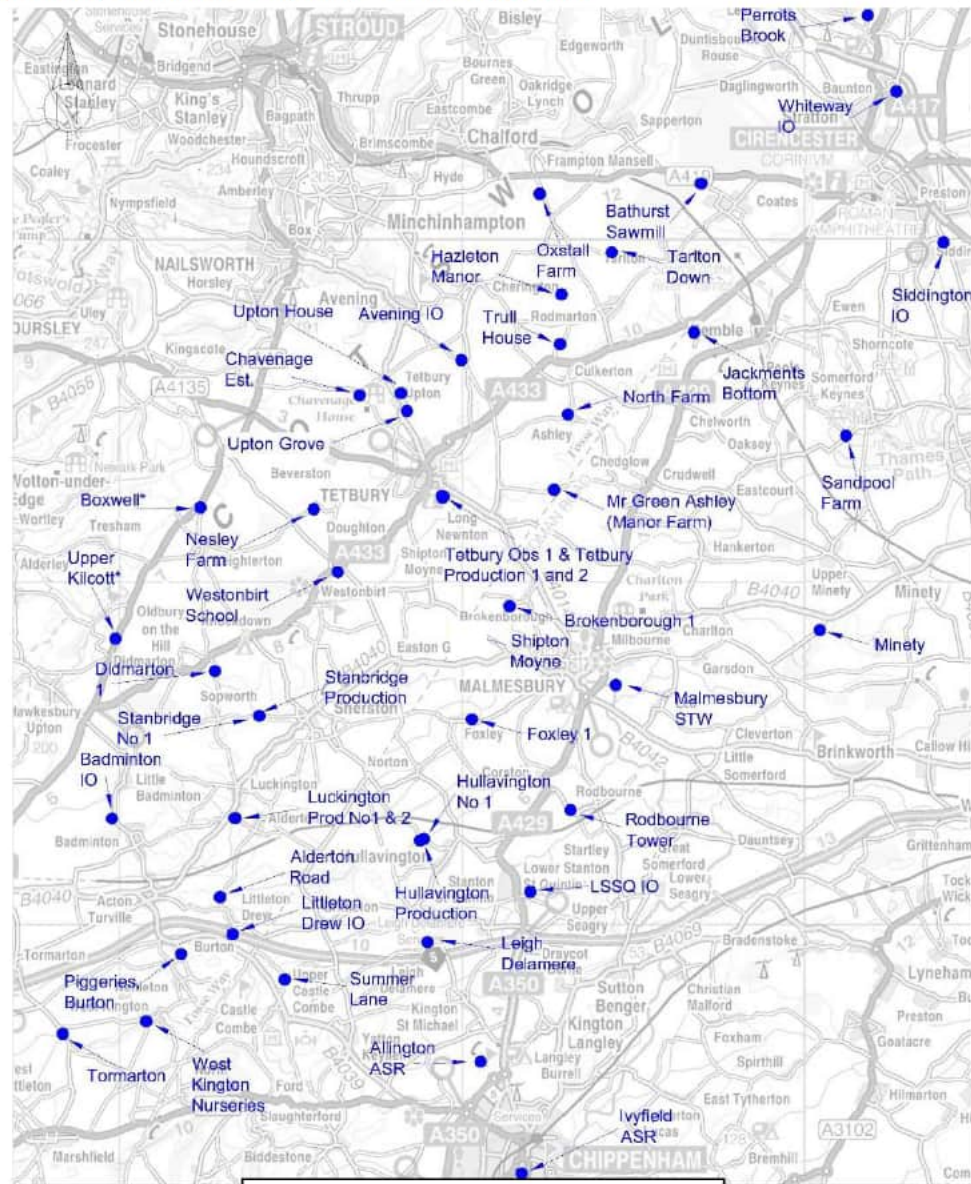
<sup>1</sup> Based on 2016 re-rating

It should be noted that the trigger/target flow at St John’s is nearly half that of the trigger flow at Fosseway located approximately 7 km upstream. This is due to a ‘losing’ reach along the river between these two points. During the summer and autumn months when groundwater levels fall below the base of the river bed, the underlying geology and structure allow river bed leakage to occur resulting in a loss of river flow. The mechanisms affecting river flow on both the Sherston Avon and Tetbury Avon are discussed in more detail in Section 3.

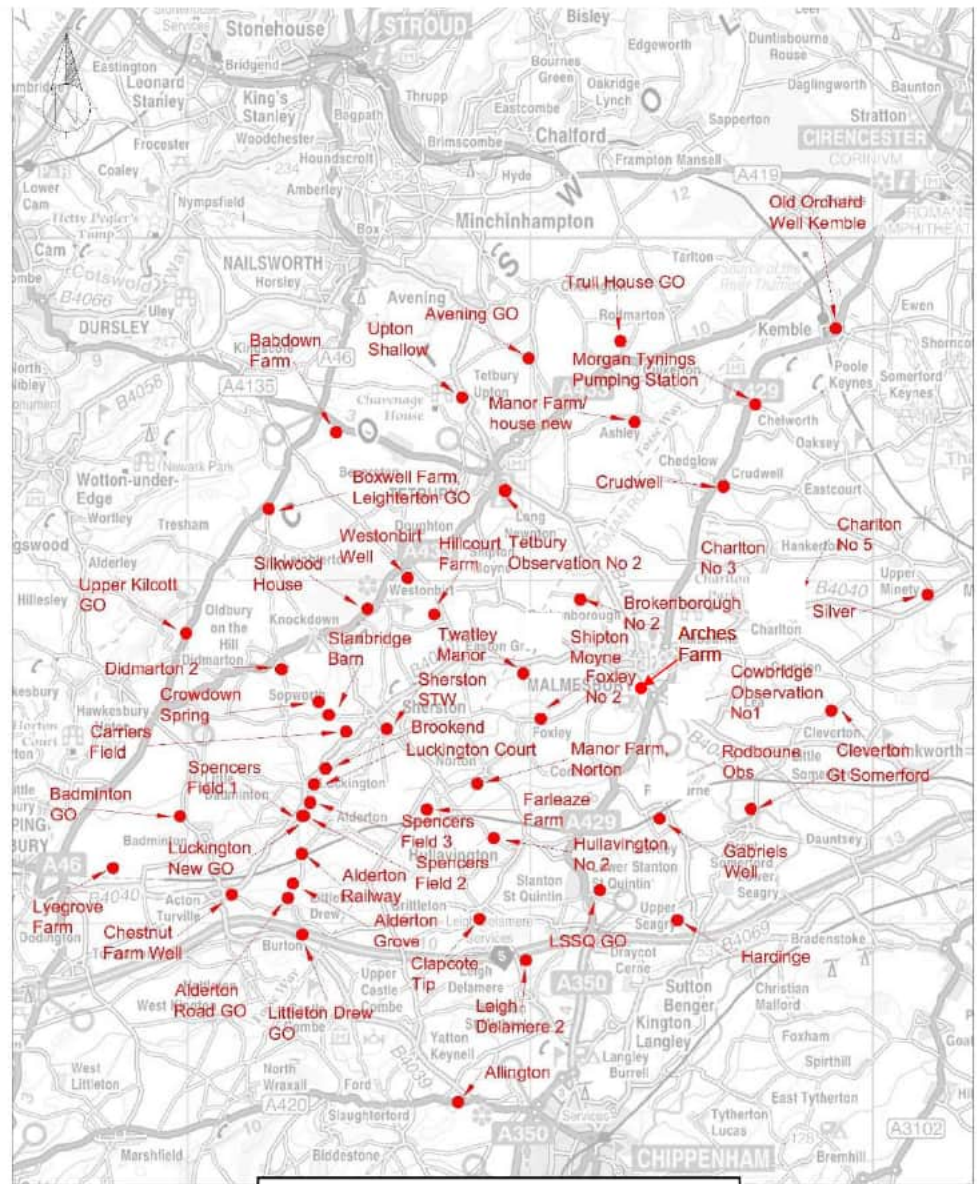
### River Flow Hydrographs

Long-term river hydrographs recorded at Fosseway, Brokenborough and Great Somerford are shown on Figure 7. The Fosseway is now a ‘trigger’ site, which instigates SS, but flow can recess below the trigger flow. The changes to stream support arrangements and other OA changes are evident on Figure 7, with target flows being typically maintained from July 1995 onwards. Hydrographs for these gauging stations from 1995 to 2016 are shown on Figure 8; also plotted on Figure 8 is the available data from St John’s Bridge Combined and Abbey Weir. In addition to the hydrographs Figure 8 also shows the actual amount of stream support water added upstream of that gauging point to maintain the target flow. Figure 8 shows that since July/Aug 1995, when the amount of SS was increased above the current licensed rates, target flows have been maintained (except for occasional pump failures). The dip below the Great Somerford prescribed flow in 2013 is examined in Section 3.3.7.

Restoring Sustainable Abstraction – Malmesbury Avon



Inferior Oolite monitoring boreholes



Great Oolite monitoring boreholes

Figure 6 Groundwater level monitoring points

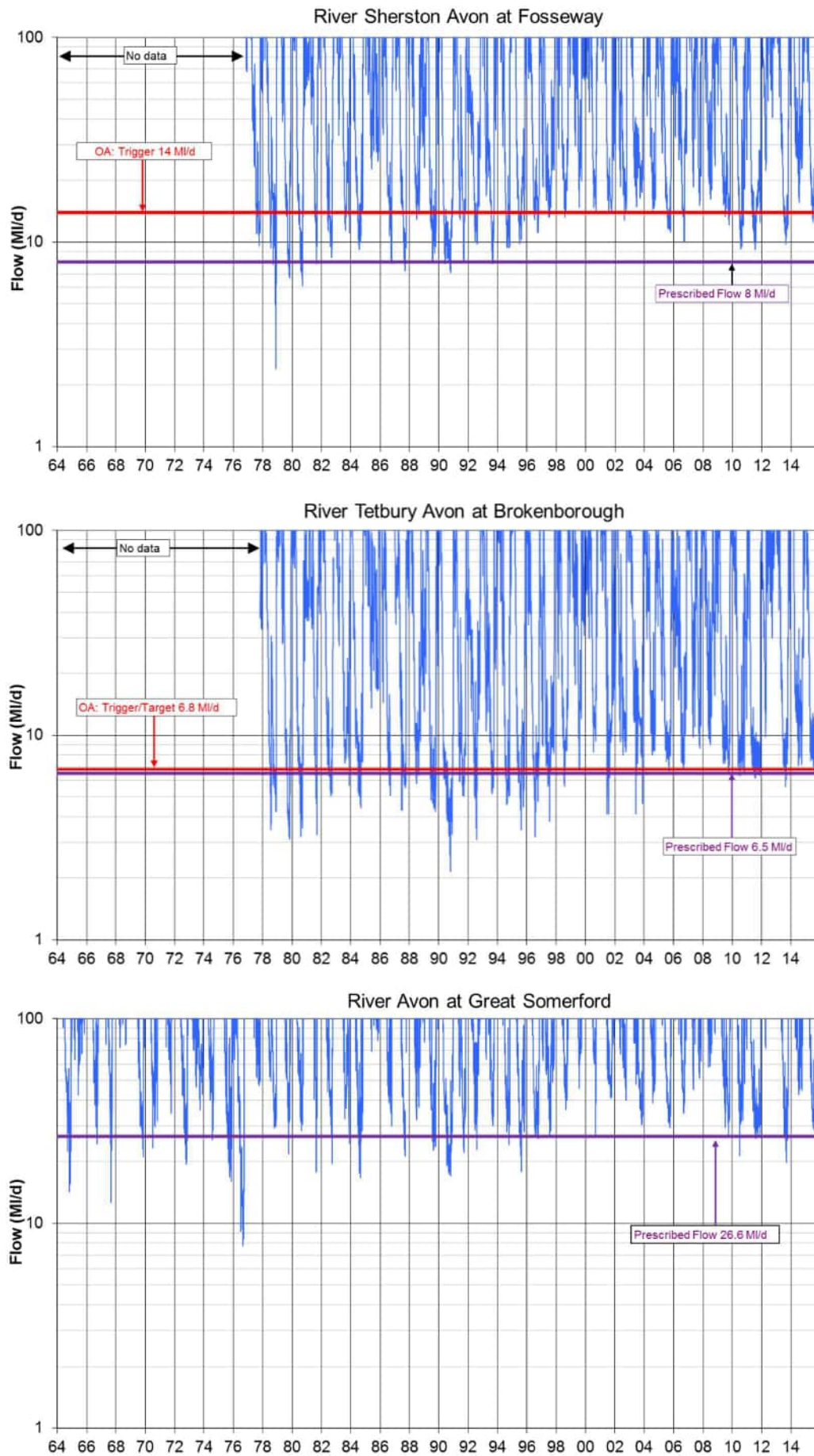


Figure 7 Flow in the River Avon at Prescribed Flow locations

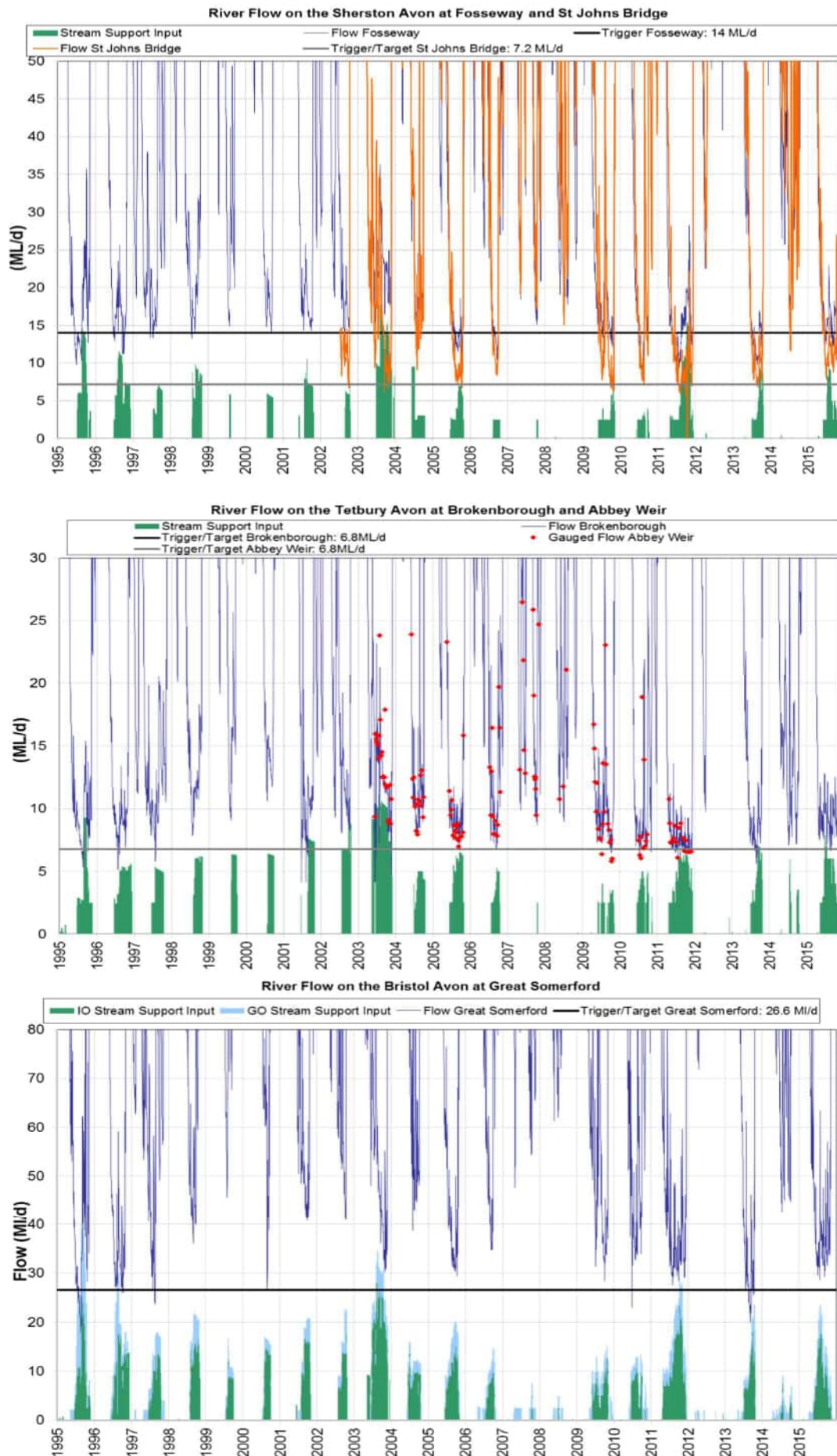


Figure 8 River flow hydrographs 1995 to 2009, plus stream support input

## 2.6 Public water supply abstraction sources

The location of PWS sources in the Malmesbury Avon catchment are shown on Figure 2. The sources draw water from both aquifers; Wessex Water sources abstract water from the Great Oolite aquifer and Bristol Water abstract water from the Inferior Oolite aquifer. However, the construction of the Bristol Water source at Shipton Moyne allows water to be drawn from both aquifers.

The annual abstraction total for PWS from the Great Oolite and Inferior Oolite aquifers from 1970 to 2015, within the Malmesbury Avon catchment are shown on Figure 9. Shipton Moyne has been assumed to be an Inferior Oolite source on Figure 9, but a component of the water is obtained from the Great Oolite.

### 2.6.1 Wessex Water – Great Oolite

Wessex Water takes water from the confined Great Oolite aquifer from five sources located around Malmesbury (Figure 2); Charlton, Cowbridge, Milbourne, Park Road and Rodbourne. These sources comprise the 'Malmesbury Groundwater Scheme'; however, Park Road has not been used since 1996. The annual output from each source between 1970 and 2015 is shown on Figure 9 (cumulative histogram).

The following observations are made from the PWS output shown on Figure 9:

- The full annual licensed quantity has never been abstracted (14540 MI/a);
- During the 1970s the annual abstraction total ranged between 4600 MI/a to 6094 MI/a. A steady increase in abstraction totals occurred through the 1980s. By the 1990s the abstraction total had almost doubled compared to the annual totals in the 1970s: ranging from 9073 MI/a to 11014 MI/a;
- Abstraction from Charlton PWS has been relatively constant between 1969 and 2003: typically, 3200 MI/a;
- The use of Rodbourne PWS during the 1970s was between 600 and 900 MI/a. During the 1980s, the use of Rodbourne increased markedly and is now the main source of supply, typically 4000 to 4500 MI/a;
- Prior to the commissioning of Cowbridge PWS, Milbourne was typically abstracting 1900 MI/a. With Cowbridge in use, Milbourne abstraction totals have reduced to: 800 to 1100 MI/a;
- Abstraction from Cowbridge PWS has been relatively constant; typically 2100 MI/a (67 l/s), though under the terms of the Sol the output from Cowbridge has reduced since 2001, though higher output has occurred since the signing of the RSol;
- Park Road PWS has been used intermittently and has now been mothballed, the proposed licence variation will remove this source from the licence.

### 2.6.2 Bristol Water – Inferior Oolite

Construction of the Bristol Water source at **Shipton Moyne** was authorised in 1914, with site works commencing in 1915 and completed in 1933. The source comprises one large diameter well connected by headings (hand dug horizontal tunnels) to six boreholes, the layout of the source is shown schematically on Figure 10. The well extends to a depth of 54 m and has a diameter of 1.89 m. The well is partly brick lined and extends through the Forest Marble, Great Oolite and a few metres into the Fuller's Earth.

At the base of the Great Oolite, four headings were constructed out from the well. The headings are typically 2 m high by 1.5 m wide. The headings intercept boreholes constructed into the Inferior Oolite. The source water is abstracted from the well. The water level in the well typically represents the water level in the Inferior Oolite. However, the construction of the source means that Great Oolite water can be drawn into the well; via unlined sections of the well and through the headings. The abstracted water quality also indicates that both aquifers contribute water, with elevated nitrate levels compared to other Inferior Oolite sources. A long standing Bristol Water assumption is that the source water made up of 50% Great Oolite and 50% Inferior Oolite water.

Records of water level and abstraction rate from the Shipton Moyne source extend back to 1935 (Bromley, 1975). From 1935 to 1961 average pumped water levels declined from 28 to 36 m below ground level, despite the fact that abstraction rates from the late 1940s were maintained at 9.1 MI/d (3312 MI/a). The use of Shipton Moyne reduced in the 1960 with the introduction of the Inferior Oolite source at Long Newton. Under the terms of the Memorandum of Understanding, Bristol Water stopped using the Shipton Moyne source in December 1998.

The **Long Newton** source was developed in 1961. The source comprises two boreholes; both are lined to exclude water from the Great Oolite and Fuller's Earth. Both holes are completed in the Inferior Oolite, with the boreholes extending 34 m into the Bridport Sand. Water is pumped from the Long Newton source to the Shipton Moyne site for treatment and both sources operate under the same licence. Licence abstraction returns are therefore an aggregate total from both sources. Only since 1996 are individual returns available, these indicate that the abstraction ratio is 55:45 (Shipton Moyne:Long Newton).

# Restoring Sustainable Abstraction – Malmesbury Avon

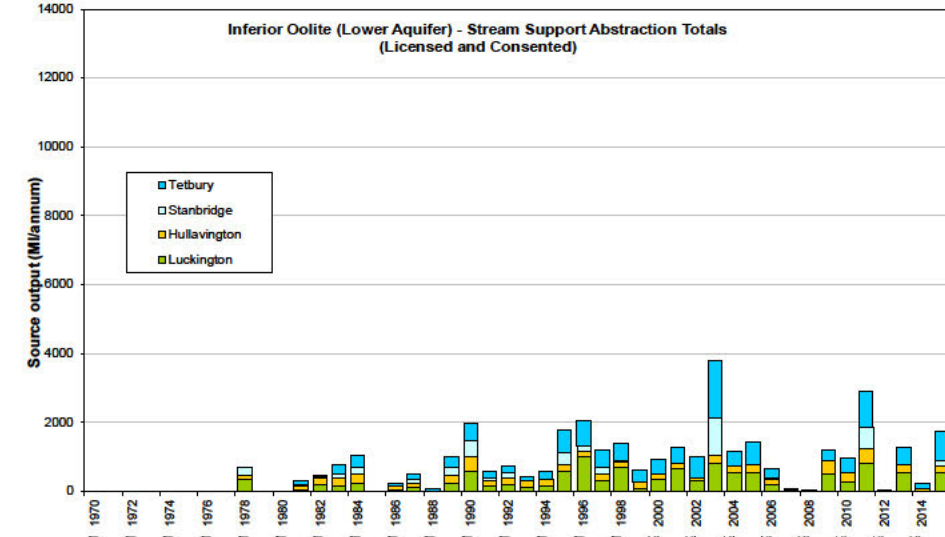
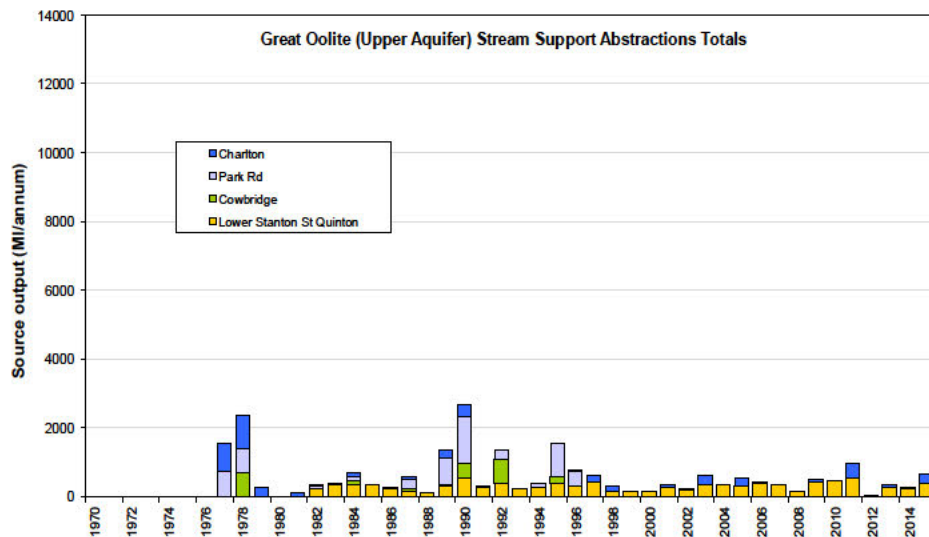
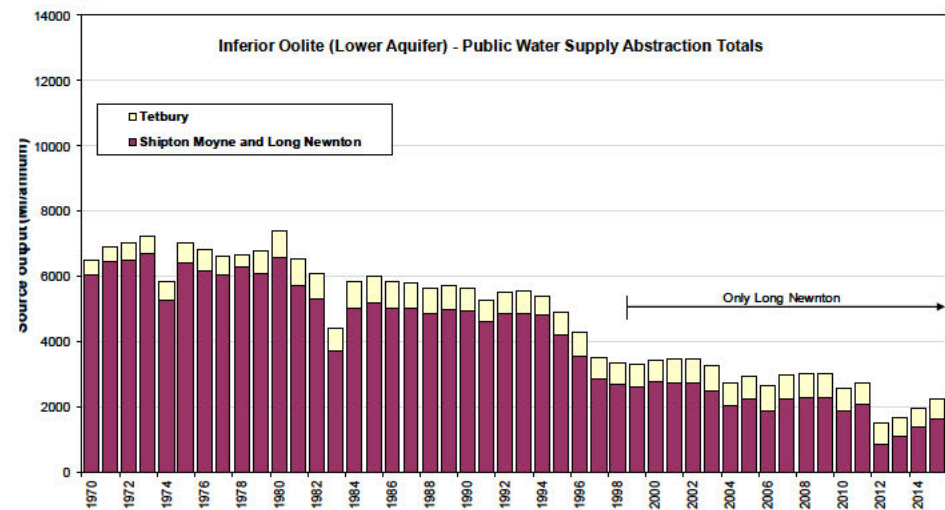
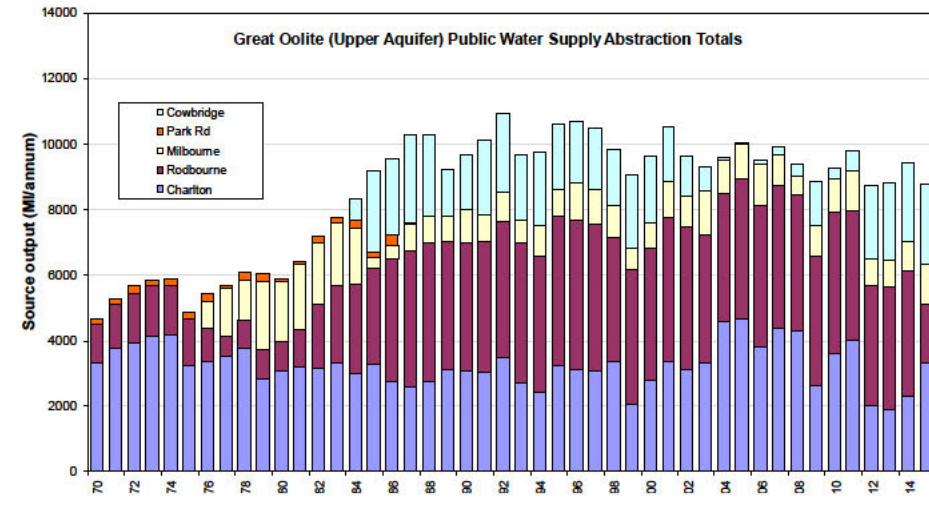


Figure 9 Annual abstraction totals from the lower and upper (Great Oolite) aquifers for PWS and stream support



SHIPTON MOYNE WELL & BOREHOLES

Heading (Adits) Lengths

- Well to No 1 c165m
- Well to No 3 c43m
- Well to No 4 c43m
- Well to No 5 c43m

Note

Heading constructed at the base of the Great Oolite

Source Bristol Water

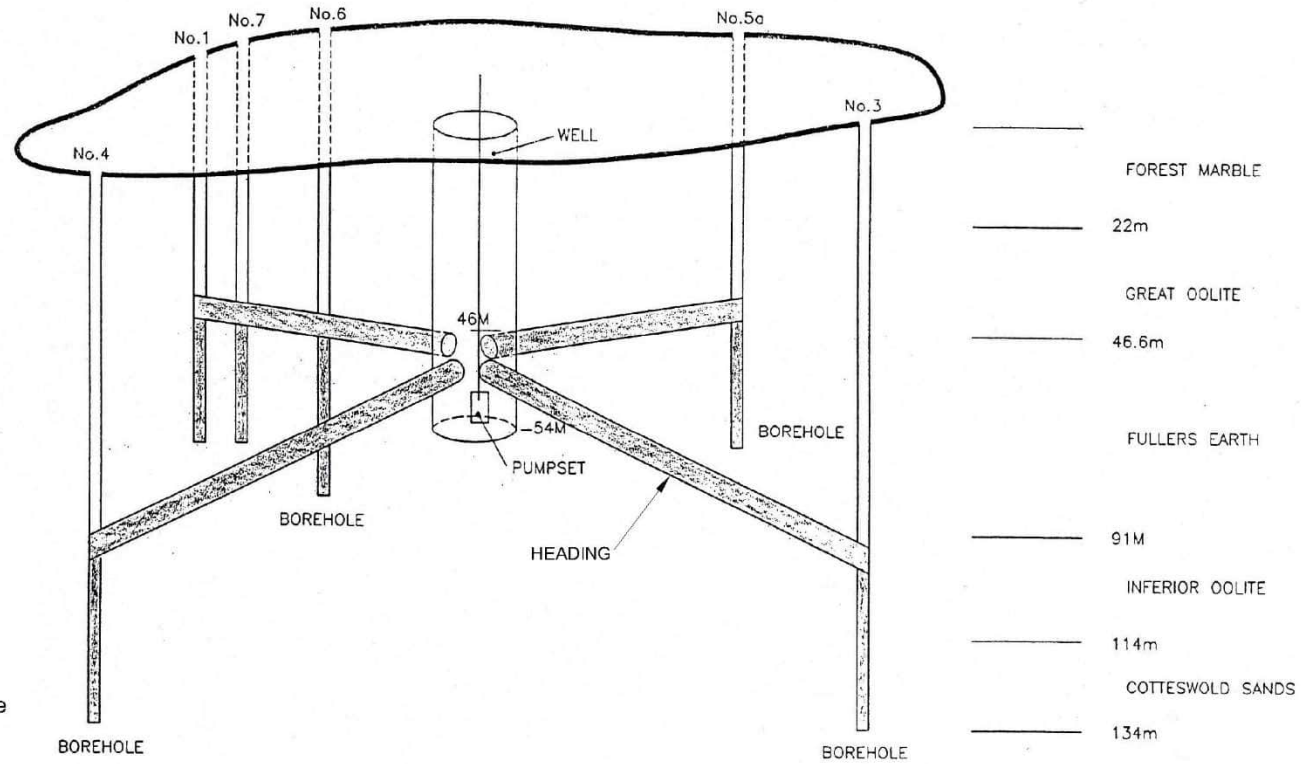


Figure 10 Schematic layout of the Shipton Moyne source

The average abstraction from the two sources is summarised in Table 5, prior to 1996 the data in Table 5 assumes a 55:45 (SM:LN) split between the sources.

Table 5 Summary of average abstraction in Ml/d from Shipton Moyne and Long Newton

Period	Shipton Moyne	Long Newton	Combined total
1970s	9.3	7.6	16.9
1980 – 94	7.7	6.3	14.0
1995 - 96	6.4	5.3	11.7
1997 – 98	4.2	3.4	7.6
1999 - 2015	0	5.7	5.7

Bristol Water operates another source utilising the Inferior Oolite: **Tetbury**. The daily use of the Tetbury source averages 1.88 Ml/d (1970-2015). The annual total abstraction, expressed as a daily average, varies between 0.97 to 2.29 Ml/d. The source comprises two boreholes: Borehole No.1 (drilled in 1927) and No.2 (drilled in 1977). The source supplies the local town of Tetbury.

## 2.7 Stream support abstraction sources and usage

Stream support pumping into the Malmesbury Avon is only undertaken by Wessex Water. The locations of the stream support sources are shown on Figure 2. Stream support water is abstracted from the Great and Inferior Oolite aquifers. The annual abstraction totals for SS from the Great Oolite and Inferior Oolite from 1970 to 2015 are shown on Figure 9.

### Inferior Oolite

Four sources abstract water from the Inferior Oolite for stream support. The four sources and the river reaches supported by the abstractions are given in Table 6.

Table 6 Inferior Oolite stream support boreholes and supported reaches

Borehole Name	River reach supported by discharge
Hullavington	Gauze Brook and Avon d/s of Gauze confluence
Luckington	Luckington branch of the Sherston Avon, Sherston Avon and Avon d/s of Sherston confluence
Stanbridge	Sherston Avon and Avon d/s of Sherston confluence
Tetbury	Tetbury Avon and Avon

Studies and test pumping trials during the development of the Malmesbury Groundwater Scheme identified impacts on river flows. Consequently, stream support boreholes were constructed in the confined Inferior Oolite near the head waters of the main river tributaries; as listed in Table 6. The rationale for the design at that time was that the two aquifers were not hydraulically connected and all abstracted water will contribute to stream flow, i.e. 100% net benefit.

Each stream support borehole is licensed to abstract up to 2.5 Ml/d to maintain prescribed flows along the Malmesbury Avon. The individual output from the four boreholes is shown on Figure 9 (annual cumulative histogram) and Figure 11 (individual monthly source outputs).

Restoring Sustainable Abstraction – Malmesbury Avon

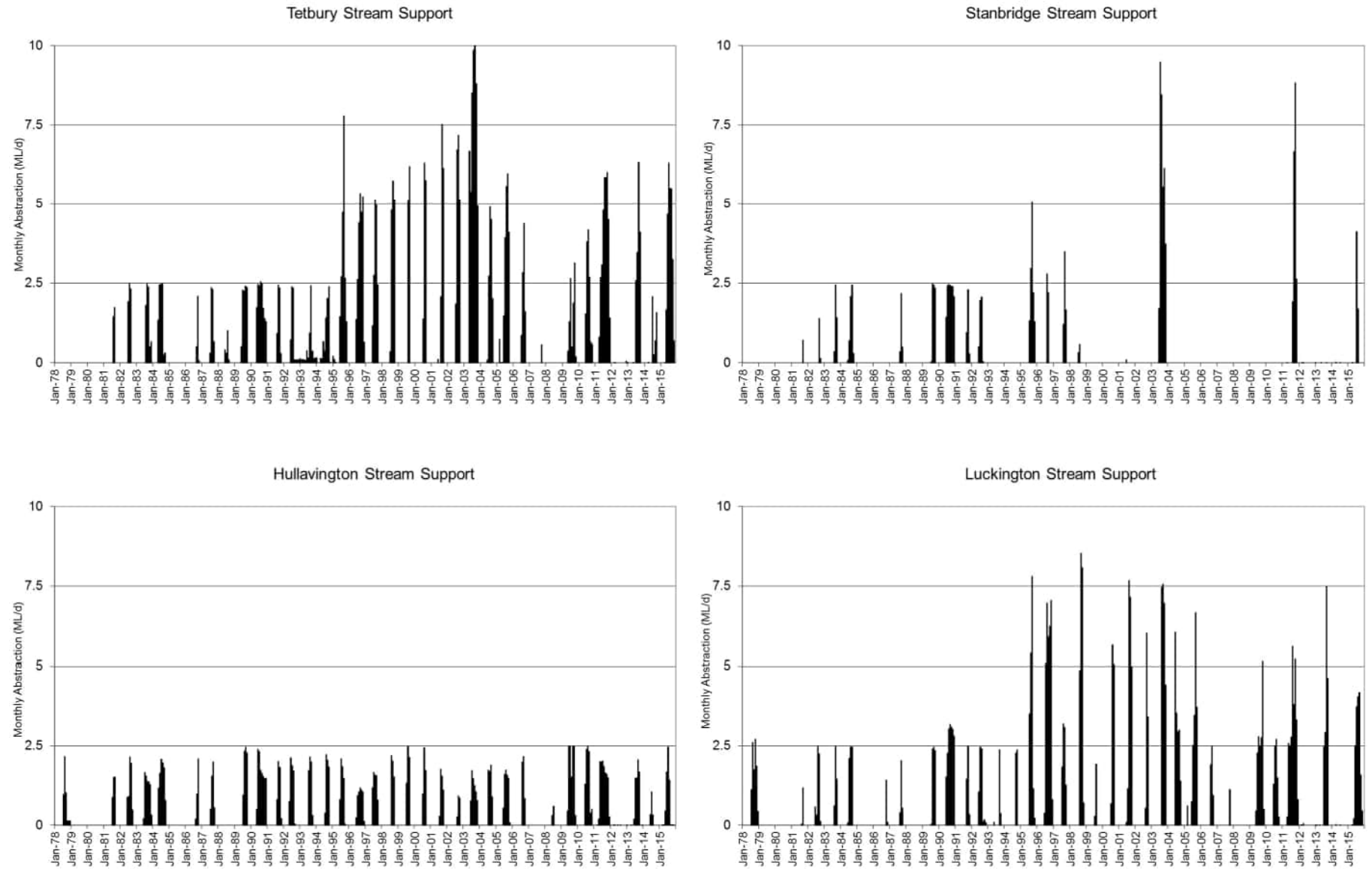


Figure 11 Inferior Oolite stream support monthly abstraction totals

In early 1995, Wessex Water instigated works to install larger capacity pumps in the SS boreholes at Luckington, Stanbridge and Tetbury. Abstraction from Luckington in 1995 commenced at 4 MI/d under a 32(3) Consent. However, the combined input from Luckington and Stanbridge was inadequate to maintain acceptable flows in the Sherston Avon in Malmesbury, with only a trickle of flow at St John’s Bridge in June 1995. In August 1995 the abstraction rate at Luckington and Tetbury were increased to improve river flows (Figure 11).

The history of permitted (licensed/consented) abstraction rates from each source are detailed in Table 7. The use of these sources above 2.5 MI/d during 1995 and ensuing trials have been authorised by Section 32(3) Consents.

Table 7 Permitted abstraction rates from the Inferior Oolite aquifer

Source	Permitted abstraction rates (MI/d)						
	Pre 1995	1995-96		1997		1998 onwards	
	Licence	Licence	Consent	Licence	Consent	Consent	Consent
Hullavington	2.5	2.5		2.5		2.5	
Luckington	2.5	2.5	7.5	2.5	7.5	2.5	7.5
Stanbridge	2.5	2.5		2.5	3.5	2.5	7.5
Tetbury	2.5	2.5	7.5	2.5	7.5	2.5	7.5

Abstraction from these sources to support river flow typically commences in June/July and ceases in late October to December.

The annual total abstraction from Luckington, Stanbridge and Tetbury between 1995 and 2015 is shown on Figure 12 as cumulative month plot for each year. Hullavington has been excluded, as this source provides flow to the river below the main sensitive reaches in and upstream of Malmesbury. The stream support annual abstraction totals used to maintain target flows since 1995 have ranged from 0 MI to 2506 MI. The 2003 annual total is higher (3565 MI), because in 2003 far more water was abstracted than actually required to maintain target flows. This high rate of abstraction occurred as part of a pumping trial to assess the yield, sustainability and impact of the proposed Sol solution. The actual SS demand (supplied by Luckington, Stanbridge and Tetbury) in 2003 to maintain target flow in Malmesbury was 1673 MI.

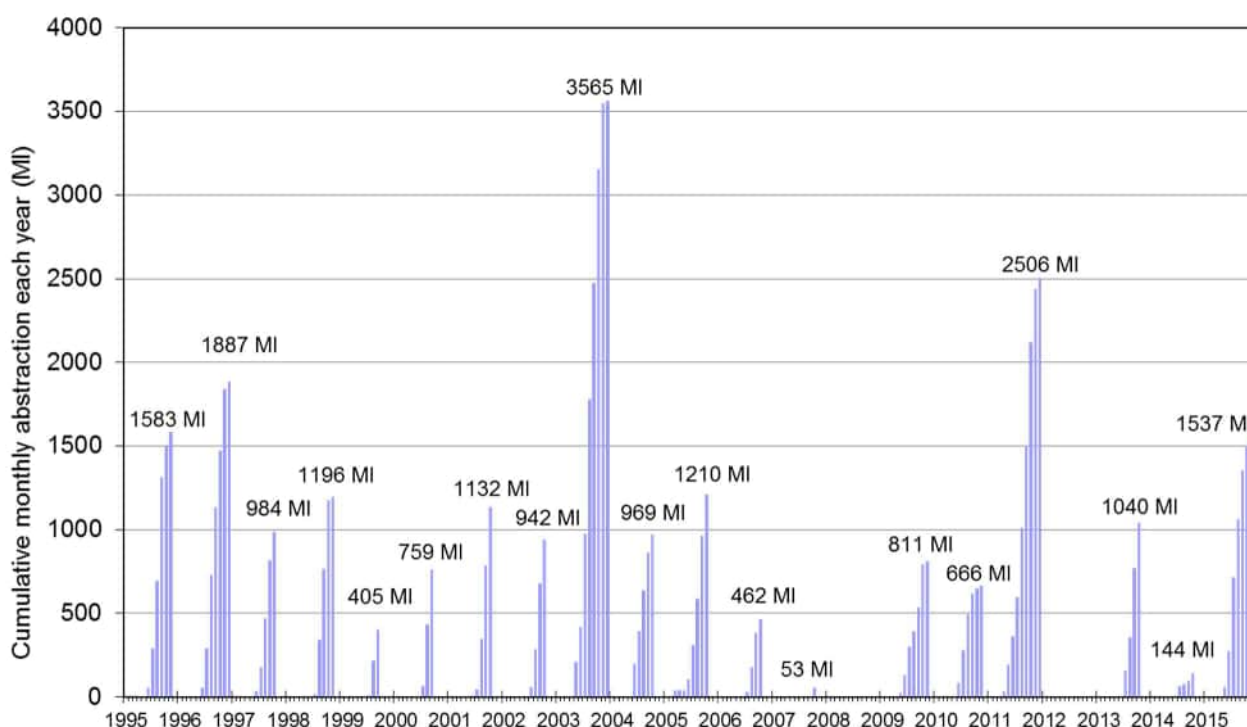


Figure 12 Cumulative monthly abstraction from Luckington, Stanbridge and Tetbury Boreholes

## Great Oolite

The Great Oolite aquifer is used for stream support at four locations. The location of these sources is shown on Figure 2 and the annual output from each source is shown on Figure 9. Table 8 details the permitted abstraction rates of these four sources. Two of these sources are still active (Charlton and Lower Stanton St Quintin), the other two sources have not been used for several years (Cowbridge and Park Rd). Park Road and Cowbridge are not used as the abstractions exacerbate the low flow situation in Malmesbury. The Cowbridge source impacts groundwater levels along the Sherston Avon in Malmesbury and the abstracted water is discharged downstream of Malmesbury. Consequently, it does not improve flows along the sensitive reaches in Malmesbury. The source at Park Rd is considered to reduce flow along the Sherston Avon in Malmesbury.

*Table 8 Permitted abstraction rates from Great Oolite aquifer*

Borehole	Permitted abstraction rate (M/d)
Charlton	2.5
Cowbridge	2.5
Lower Stanton St Quintin	2.5
Park Road	10

### 3 Impact of Great Oolite PWS abstraction on river flow

- The Malmesbury Avon is a ‘flashy’ catchment, prone to naturally low flow during periods of low rainfall
- PWS abstractions intercept baseflow to the river and during periods of low rainfall, these abstractions stop river baseflow and can cause the river reaches to become perched
- When perched, the river loses (leaks) water along the Sherston Avon as it flow through Malmesbury
- The catchment is sensitive to long ‘dry’ summers and 1990 was a more severe dry summer, in the Malmesbury Avon catchment, than 1976
- The annual stream support demand in a repeat of 1990, under the proposed licence variation, to maintain target flow in Malmesbury would be 3742 MI

#### 3.1 Introduction

The natural behaviour of the Malmesbury Avon and how this is impacted by the PWS abstractions are described in this section. This is mainly a qualitative assessment as there is no data to define conditions before PWS and SS abstractions started. In Section 3.4, the amount of stream support water required to maintain the target flows is defined. Firstly, some hydrologically and hydrogeological characteristics of the Malmesbury Avon are presented.

#### 3.2 Malmesbury Avon River – Hydrologic characteristics

The hydrology of the Malmesbury Avon is complex, due the variation in underlying geology.

The clay outcrop area results in rapid runoff following rainfall, the Malmesbury Avon is known to be ‘flashy’. Figure 13 shows the river flow response to rainfall in late October 2003, when a soil moisture deficit (SMD) was still present. Figure 13 shows an increase in river flow even though the rainfall total did not exceed the SMD.

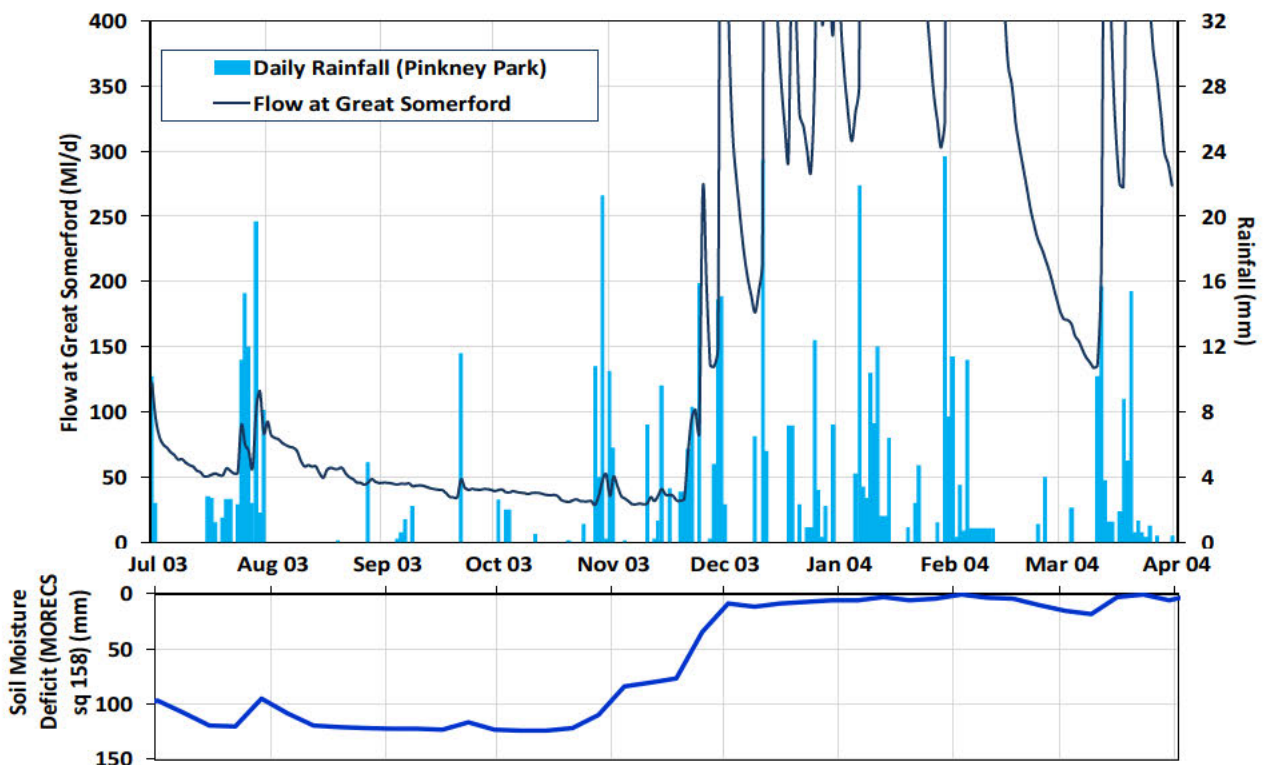


Figure 13 River Avon response to rainfall and soil moisture deficit

In addition to the clayey soils directing runoff to the rivers, runoff can rapidly enter the Great Oolite via swallow holes. Consequently, the Great Oolite aquifer recovers quickly following the onset of winter rains.

Figure 14 shows the Great Oolite water level at Brokenborough No.2 and Foxley No.2 during the latter part of 2003 and early 2004. As with the river flow, the groundwater level rose at both these locations whilst a soil moisture deficit was still present. During the 2003/04 winter the Great Oolite water levels had recovered to a typical winter maxima (>75 mAOD) within two months (by the end of December), with slightly above average rainfall occurring (November and December rainfall total was 190 mm).

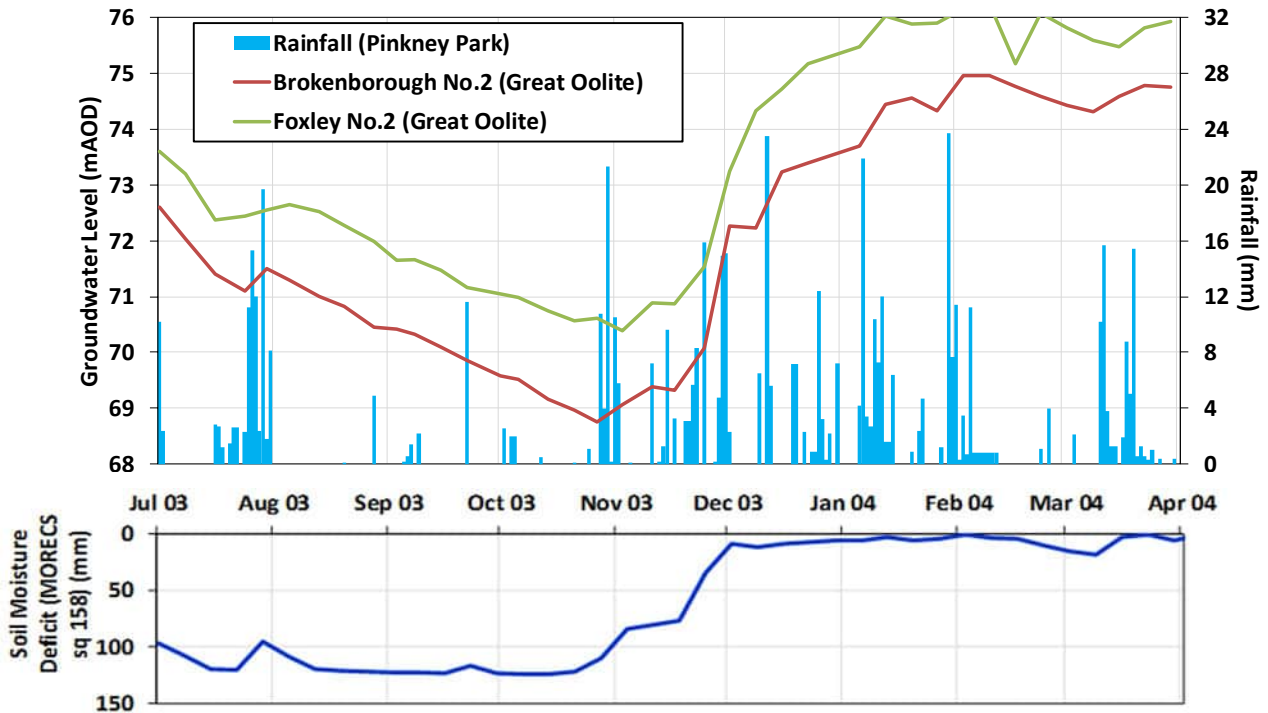


Figure 14 Great Oolite response to winter rainfall and soil moisture deficit

The rapid recovery of Great Oolite water levels, and river flows, is observed in previous years, as shown by the Foxley No.2 hydrograph in Figure 15. Another feature of the Great Oolite water level is that it typically recovers to similar winter maxima, >75 mAOD, independent of the amount of recharge. The winter (Nov-Mar) recharge totals over the period (1970 to 2015) have been ranked in order of increasing recharge. Figure 15 highlights the five years with the lowest recharge (1 to 5) and five years with the highest recharge totals (41 to 45). These data show that the Foxley water level after a dry year (2004/05 is ranked the 5<sup>th</sup> lowest recharge winter) was the same as after a wet winter (1994/95 is ranked the 41<sup>st</sup> lowest recharge winter i.e. 5<sup>th</sup> wettest winter). Therefore, even low winter recharge is sufficient to replenish ('fill up') the Great Oolite aquifer.

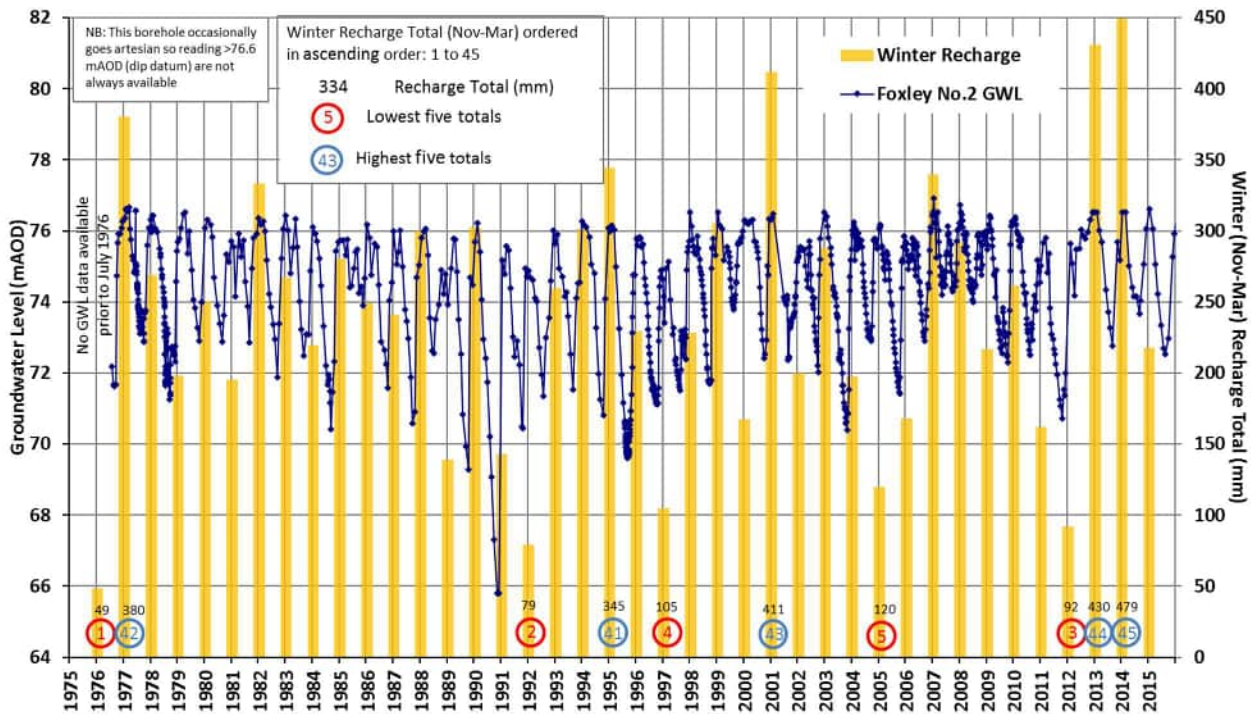


Figure 15 Great Oolite hydrograph and winter recharge totals

This behaviour was also observed during 1990. During 1990 several months of below average rainfall occurred from March onwards and with high rates of PWS occurring Great Oolite water levels declined to their lowest ever recorded level (Figure 15). With water levels so low it is envisaged that stream support would be required until the aquifer had ‘filled’ up. However, in 1990 river flows were above the target by around 12<sup>th</sup> December following modest amounts of rainfall in November and early December, although actual stream support continued until the end of December at Luckington, Stanbridge and Tetbury. The flows above the targets occurred whilst a soil moisture deficit was still present and the Great Oolite water levels were still recovering. This highlights the runoff component of the catchment and groundwater contributions from areas not impacted by the PWS abstraction, e.g. fault controlled springs, Forest Marble and Cornbrash.

Analysis of the 1990 data indicates that when the flow at Great Somerford was sustained above 50 MI/d, stream support was not required. Regarding the 1975/76 winter, which had the lowest recharge total in the last 45 years, the flow at Great Somerford remained above 50 MI/d from December to late April. Based on these observations it is concluded that even with high PWS usage (Section 3.4.1), SS from the Inferior Oolite aquifer would not have been required from December 1975 to late April 1976.

In addition to rapidly ‘filling up’, the Great Oolite aquifer also releases water quickly. The aquifer needs regular rainfall events to maintain storage levels (filled up). The filling and draining in response to rainfall events produces winterbourne reaches of the Sherston and Tetbury Avon, above perennial springs, and other side tributaries. The combination of surface water runoff and groundwater discharge, can result in spate flows in the Malmesbury Avon and flooding in Malmesbury (Figure 16).



*Figure 16 Tetbury Avon at Back Bridge Malmesbury, December 1960*

### **3.3 Natural and impacted flow conditions**

#### **3.3.1 Introduction**

Abstraction of groundwater has been occurring across the Malmesbury Avon catchment for over 80 years and no data exists prior to this abstraction. Therefore, it is difficult to accurately assess what the natural river flow conditions would be like. However, despite this limitation, it is possible with the available historical data to prepare a conceptual understanding of how river-groundwater interaction works, though some uncertainty remains and hence qualitative assessments are sometimes used. The following conceptual model has been produced to outline hydraulic conditions during both natural and pumping conditions. The river network has been divided into the Sherston Avon down to Malmesbury, the Tetbury Avon from Tetbury to its confluence with the Sherston Avon at Malmesbury, and the Avon from Malmesbury to Great Somerford.

### 3.3.2 Sherston Avon – natural flow conditions

**Winter** – The Great Oolite aquifer is full and the river accretes along its entire length including the winterbourne section at the top end of the river above Luckington and at Didmarton. The groundwater level within the confined part of the aquifer is higher than the river level and therefore there is the potential for groundwater to move up faults and provide baseflow to the River Avon. Higher level springs draining limestone beds of the Forest Marble Formation also augment flows to the river.

**Spring/summer/autumn** – The conceptual behaviour of the river during the summer is shown on Figure 17. The high permeability of the Great Oolite means that once recharge stops, the Great Oolite drains quickly and winterbourne reaches dry to fault controlled perennial springs at Hancock’s Well and Crow Down on the Luckington and Stanbridge arms of the river, respectively (Figure 18). The faults here are thought to act as a barrier to flow, where more permeable strata has been moved against low permeability strata, effectively ‘holding up’ the water resulting in the springs. Downstream of these springs the river is likely to leak as groundwater levels will again have recessed below the base of the river bed resulting in a perched river. Consequently, there will be a reduction in flow along these two reaches down to Sherston where the two arms join. From here leakage through the stream bed may continue until the perched river starts to flow over the Forest Marble near Sherston STW. Further downstream, between Pinkney and Fosseway, baseflow and springs issuing from limestone bands within the Forest Marble provide additional flow to the river. Downstream of Fosseway, the Forest Marble clay is at outcrop and little increase in flow is expected. However, towards Malmesbury the river continues to accrete where Great Oolite water flows up faults (due to piezometric heads in the confined Great Oolite being above river level) into the Avon.

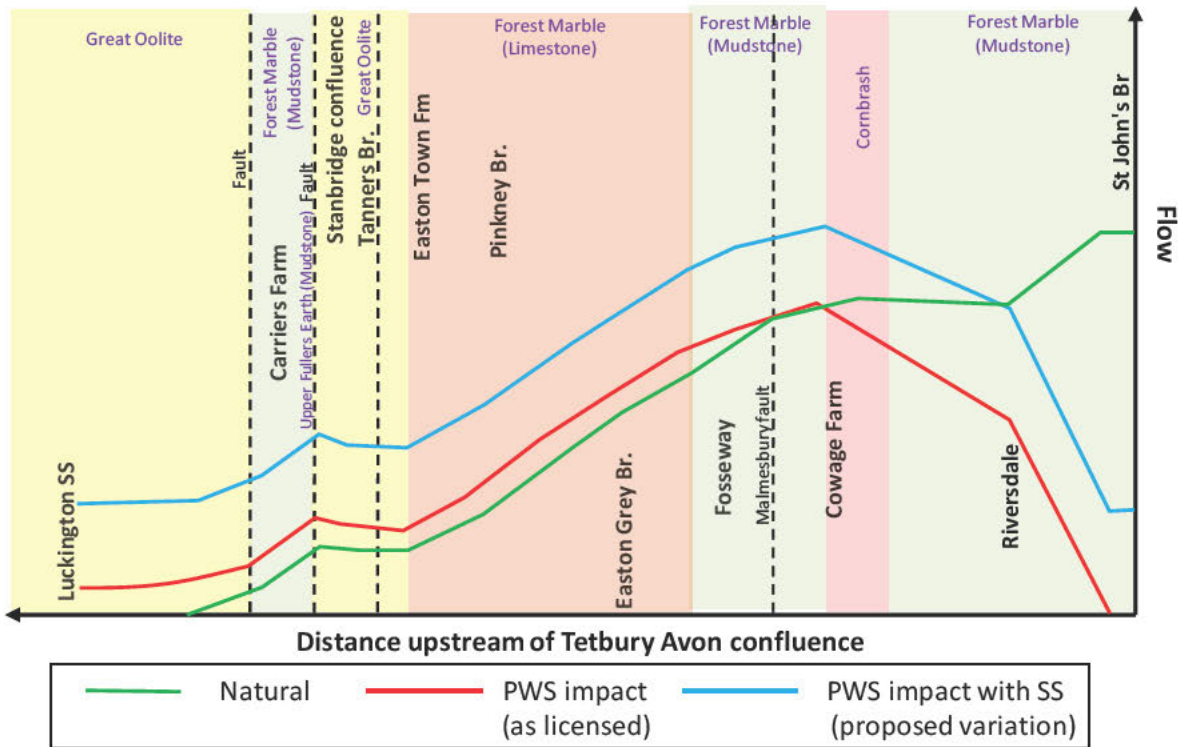


Figure 17 Sherston Avon conceptualised summer flow profiles under natural, with PWS and SS as licensed and with PWS and SS occurring under the proposed licence variation

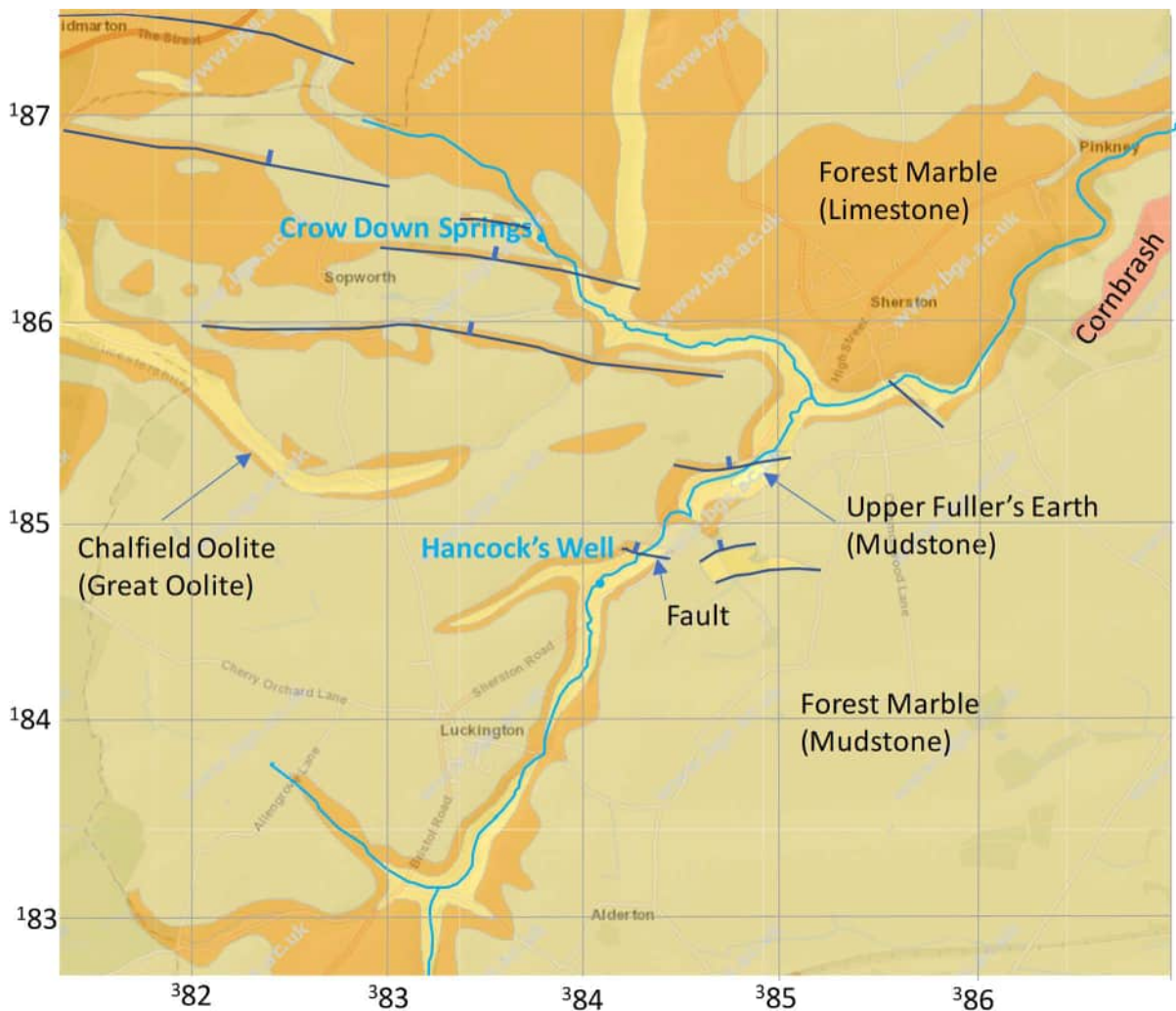


Figure 18 Sherston Avon outcrop geology upstream of Pinkney to Luckington

### 3.3.3 Sherston Avon – impacted flow conditions

**Winter** – During the winter a similar scenario to that recorded under natural conditions is observed. The aquifer is full and the river accretes along its entire length.

**Spring/summer/autumn**– In spring, groundwater levels begin to recede and the flowing winterbourne reach migrates downstream. Springs continue to emerge at the fault controlled springs at Crow Down and Hancock's Well. These are not considered to be impacted by the PWS abstraction, the fault acting as a barrier. Further downstream of these springs the recessing groundwater levels fall below the base of the river bed resulting in river bed leakage and a reduction in river flows. Abstraction may exacerbate this natural situation.

Spot flow gaugings along the Sherston Avon in 1995 show the flow profile with the PWS sources active (Figure 19). Figure 19, also shows the outcrop geology underlying the river, and the amount of stream support occurring at Luckington and Stanbridge when the gaugings were undertaken. Downstream of the Stanbridge confluence the river is perched over the Great Oolite outcrop and a small loss of flow is seen. It is not certain whether the low groundwater level is due to abstraction or a natural feature. As the river flows onto the Forest Marble, there is an increase in flow, even with the PWS source active. This flow from the Forest Marble limestone aquifer shows a degree of separation from the underlying Great Oolite aquifer, presumably due the presence of thin clay horizons with the Forest Marble.

The river also gains flow as it flows over the predominately clay Forest Marble outcrop. This may be due to limestone bands within this formation being of sufficient thickness to provide a noticeable flow to the river. Alternatively, there is Great Oolite water entering the river through the Forest Marble via the Malmesbury fault. However, the Great Oolite groundwater level (Foxley No.2) on the downstream side (south side) is too low to allow this. Faulting, though not mapped, is considered to bring the Great Oolite close to surface in Malmesbury and allow groundwater to flow to the river. However, the PWS abstractions can cause this natural flow direction to reverse, such that a loss of flow (leakage) is seen as the river flows through Malmesbury from Riversdale to St John's Bridge. The leakage rate can exceed the flow in the river at Riversdale, within the currently licensed rates of stream support, resulting in the river drying, shown conceptually as a red line on Figure 17.

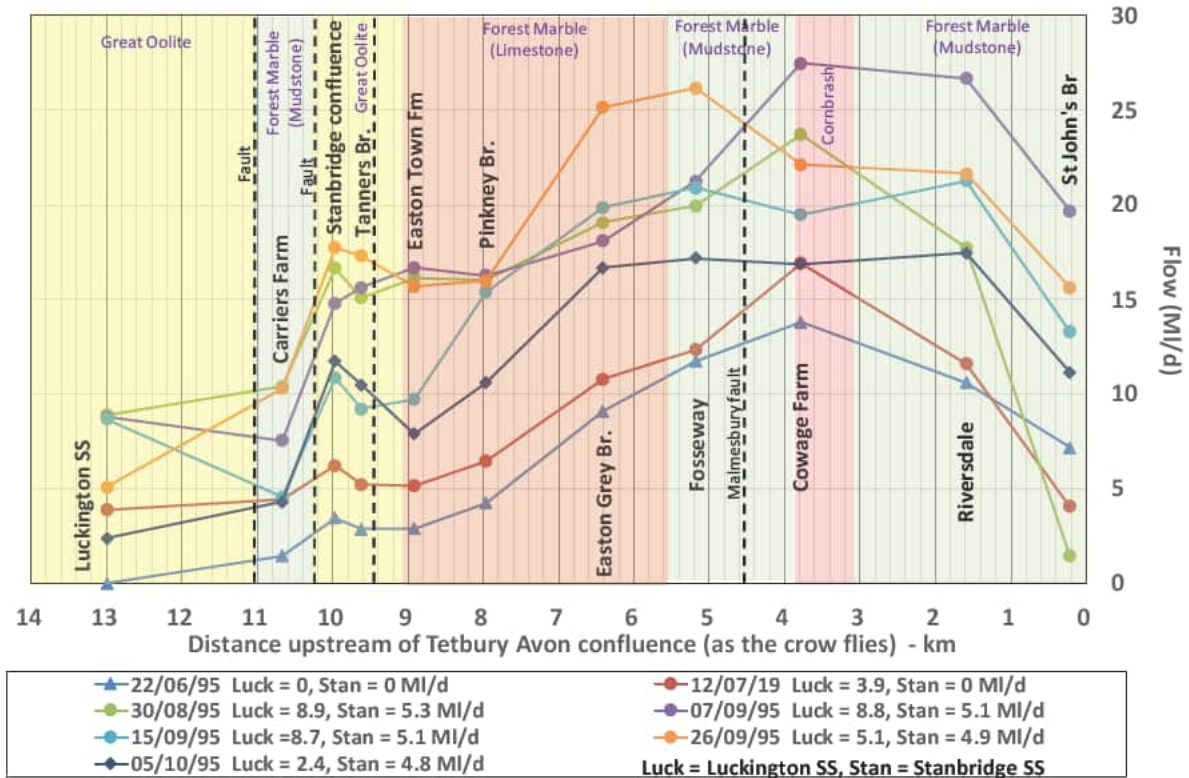


Figure 19: Sherston Avon – flow profiles based on spot gauging in the summer of 1995

Since July 1995, extra stream support has been added to exceed the leakage rate and to maintain the target river flow, shown conceptually as the blue line on Figure 17.

### 3.3.4 Tetbury Avon – natural flow conditions

The conceptual understanding under natural and impacted conditions (as licensed and the proposed arrangement), in the spring, summer and autumn is shown on Figure 20.

**Winter/spring** – The Great Oolite aquifer is full and flow in the river emerges from springs issuing from the Great Oolite and Forest Marble limestones to the northwest of Tetbury. The river continues to accrete along its length down to Malmesbury with flows augmented by springs and small channels draining the Forest Marble. In the spring, the spring head recesses to Tetbury. Downstream of Tetbury, to the confluence with the Sherston Avon the river predominantly flows over Forest Marble mudstones, but faulting brings the Great Oolite to surface upstream of Brokenborough. High Great Oolite groundwater piezometric heads potentially result in an upward movement of water through the Forest Marble, or via outcrop, discharging into the river and increasing baseflow.

**Summer/autumn** – In the summer a similar behaviour is expected, but with reduced spring flows and baseflow as groundwater levels recess.

### 3.3.5 Tetbury Avon – impacted flow conditions

**Winter/spring** – During the winter a similar scenario to that recorded under natural conditions is observed. The aquifer is 'full' and flow in the river emerges from springs issuing from the Great Oolite and Forest Marble limestones to the north west of Tetbury. The river continues to accrete along its length down to Malmesbury with flows augmented by spring issues and small channels draining the Forest Marble.

**Summer/autumn** – The PWS impact becomes pronounced through the summer. The baseflow being reduced until it is stopped downstream of Slads Farm to Malmesbury (Abbey Weir) i.e. by August 2005 (Figure 21). Gauging locations are shown on Figure 2. From May 2005, there is no gain from Brokenborough to Abbey weir. This behaviour is seen in other summers. Stream support seeks to partly replace this baseflow. Stream support is effective because although groundwater levels can be below the stream bed, e.g. in 2005, the bed of the river provides an effective seal, such that no loss of flow (within gauging error) is seen along the Tetbury Avon under SS conditions (Figure 21).

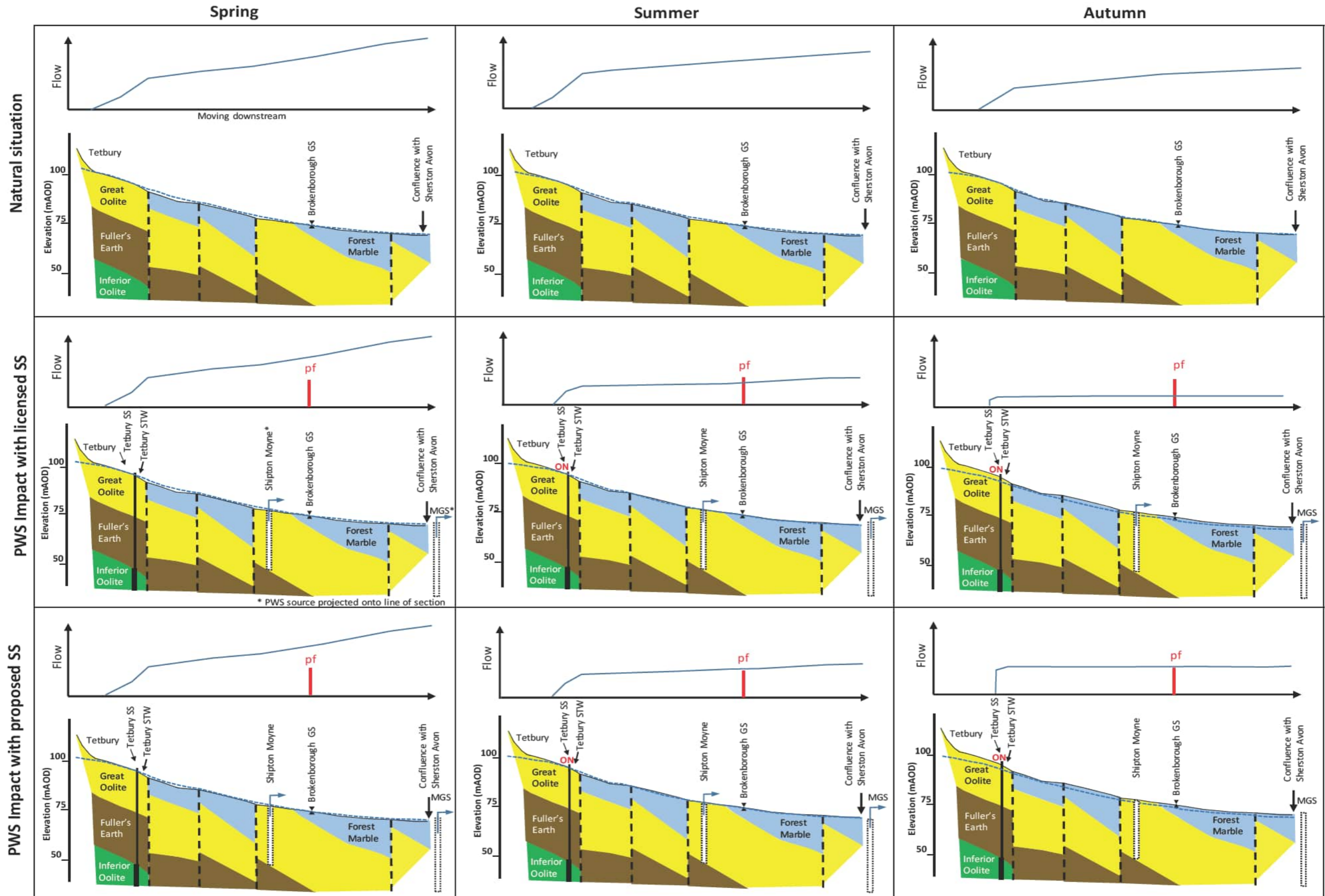


Figure 20 Tetbury Avon - conceptualised flow profiles (spring, summer and autumn) under natural flow conditions, with PWS and SS occurring as licensed and with PWS and SS occurring as proposed

pf = prescribed flow

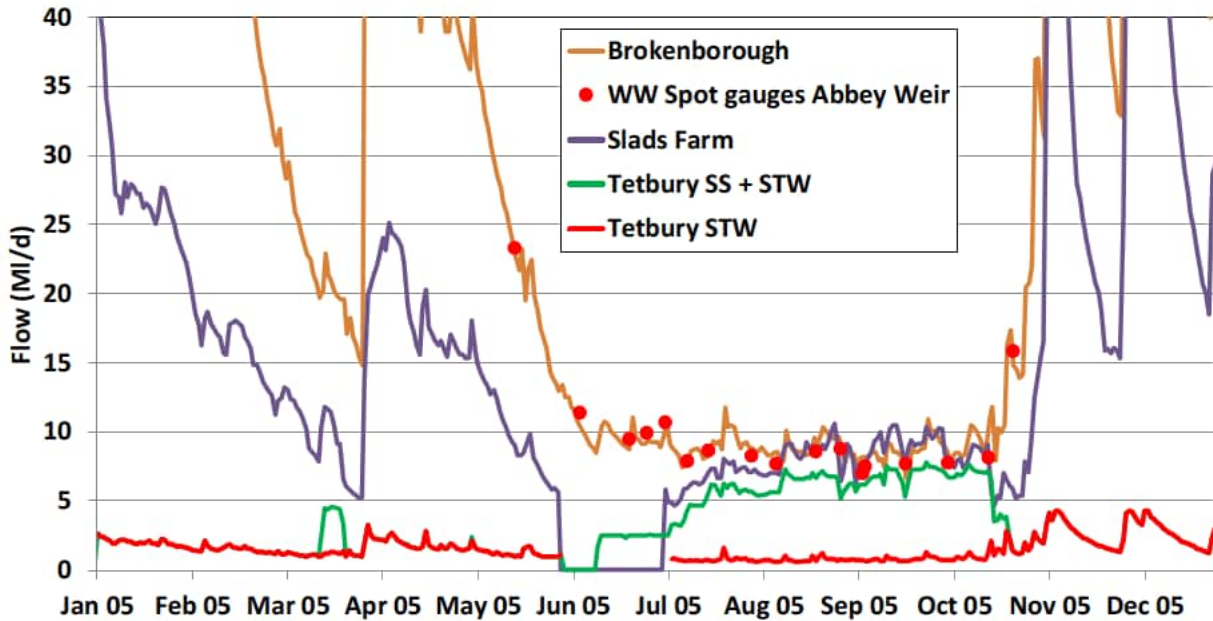


Figure 21 Tetbury Avon flow at Slads Farm, Brokenborough and Abbey Weir, plus Tetbury STW and SS input rates in 2005

A gain of flow is seen upstream of Slads Farm under low flow conditions. This inflow is probably associated with a geological fault (Tetbury fault) that crosses the Avon between the Slads Farm site and STW and SS inputs. The fault results in the Great Oolite (upstream) abutting the Forest Marble clays, such that groundwater backs up in the Great Oolite forming a spring. However, the gain does recess to a constant level, which is hard to explain, as groundwater levels are recessing. This feature is also seen in 2011, a notable recent dry year (Figure 22). This chart is similar to the 2005 plot (Figure 21), but includes a line to show the flow at Slads Farm, minus the SS and STW inputs. By May 2011 the flow at Slads Farm is constant, and remains so through June and into early July. The data post July is difficult to reconcile, as the 'gain' increases, though the Great Oolite head is recessing at Brokenborough and Tetbury. The apparent 'gain' increase may in reality be due to weed growth, backing up water into the flow structure.

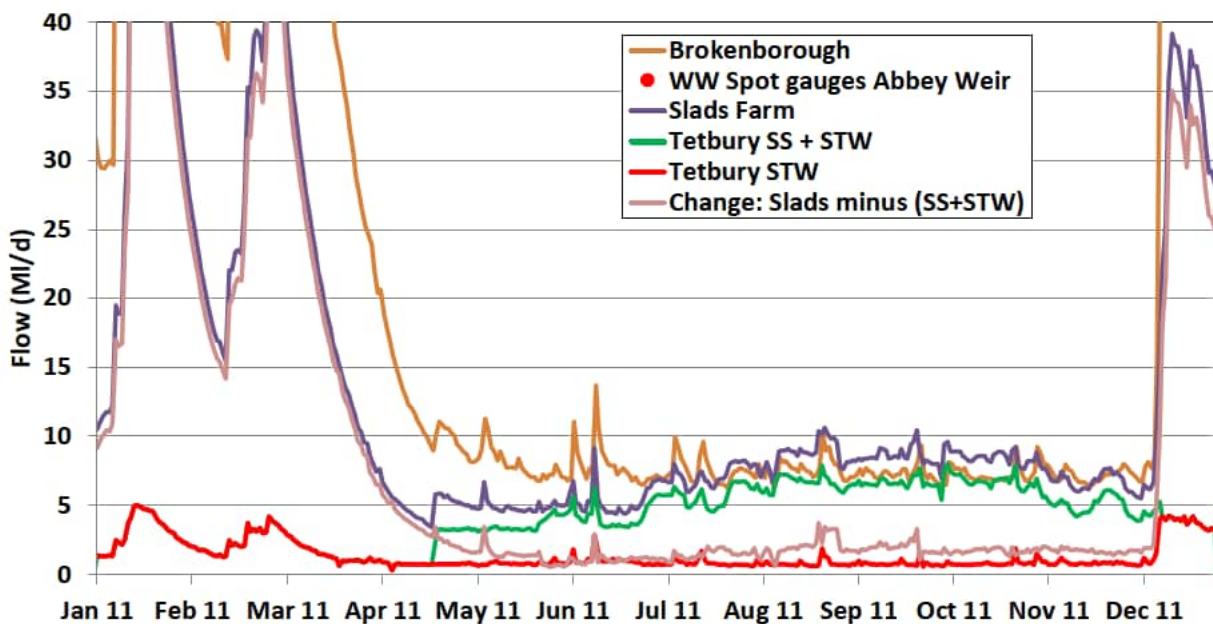


Figure 22 Tetbury Avon flow at Slads Farm, Brokenborough, Tetbury STW and SS input rates in 2011, plus flow at Slads minus the STW and SS input

### **3.3.6 Avon from Malmesbury to Great Somerford – natural flow conditions**

The river along this reach is underlain by secondary aquifers (Forest Marble and Cornbrash) and un-productive strata i.e. Kellaway Clays. These will provide little or no baseflow to the river. However, a more substantial natural inflow may be occurring from the Great Oolite and Inferior Oolite aquifer. As examined in Section 3.3.3. the Great Oolite provides flow to the Avon in Malmesbury. It is postulated that faulting, possibly an extension of the Corston Fault, allows groundwater in the Great Oolite aquifer to flow in to the Avon. Further faults (e.g. Griffins Barn) and possibly un-mapped faults downstream of Malmesbury, may also be active in providing a route for Great Oolite water to enter the Avon. In addition, these faults probably provide the route for Inferior Oolite water to leave the aquifer and enter the Avon. In the absence of pre-abstraction data, it is not possible to quantify this flow, but a gain in flow may occur naturally throughout the year along this reach.

In addition to baseflow to the main river, the Great Oolite and Forest Marble/Cornbrash aquifers are drained by three streams which flow into this reach: Woodbridge Stream, Gauze Brook and Rodbourne Stream. These streams are fed by fault controlled Great Oolite springs, e.g. Charlton Park or springs at the edge of the confined layers. These streams have winterbourne reaches above these perennial heads. The catchment areas of these streams are small compared to the Sherston Avon, but a perennial flow is expected, recessing to 'low' flows during the summer, and responding quickly to winter rains.

### **3.3.7 Avon from Malmesbury to Great Somerford – impacted flow conditions**

The proposed increases in Inferior Oolite SS abstraction is unlikely to induce any significant impact upon the tributaries feeding the Lower Avon, and these streams have not been the subject of low flow complaints. The existing licence arrangements, therefore, provide acceptable river flows. However, a contribution of flow from the Great Oolite and Inferior Oolite to the Avon is expected along this lower reach. Therefore, the impact of PWS and SS abstractions along the main Avon is assessed.

To determine the flow change along the reach, the daily flow at the gauges upstream of Great Somerford have been summed, plus the Malmesbury STW effluent in flow to the river, and subtracted from the flow at Great Somerford. This exercise has been undertaken from February 2003 to 2016. This analysis starts in 2003 as this is when the St John's Bridge data is first available. The results of this analysis are contained in Appendix H (2008, 2012 and 2014 are not included as these were 'wet' summers). The 2003 analysis is shown on Figure 23 (a-i). Figure 23 shows individual hydrographs for the upstream gauges (a-f) (flow and SS input rates), a plot of Wessex Water PWS source daily rates, (g) the actual flow at Great Somerford, the sum of the upstream gauges and flow change along this reach (h). Plus, a plot of the Foxley No.2 (Great Oolite) groundwater level (i). These charts are cropped to show the spring/summer/autumn (May to Nov) behaviour.

Restoring Sustainable Abstraction – Malmesbury Avon

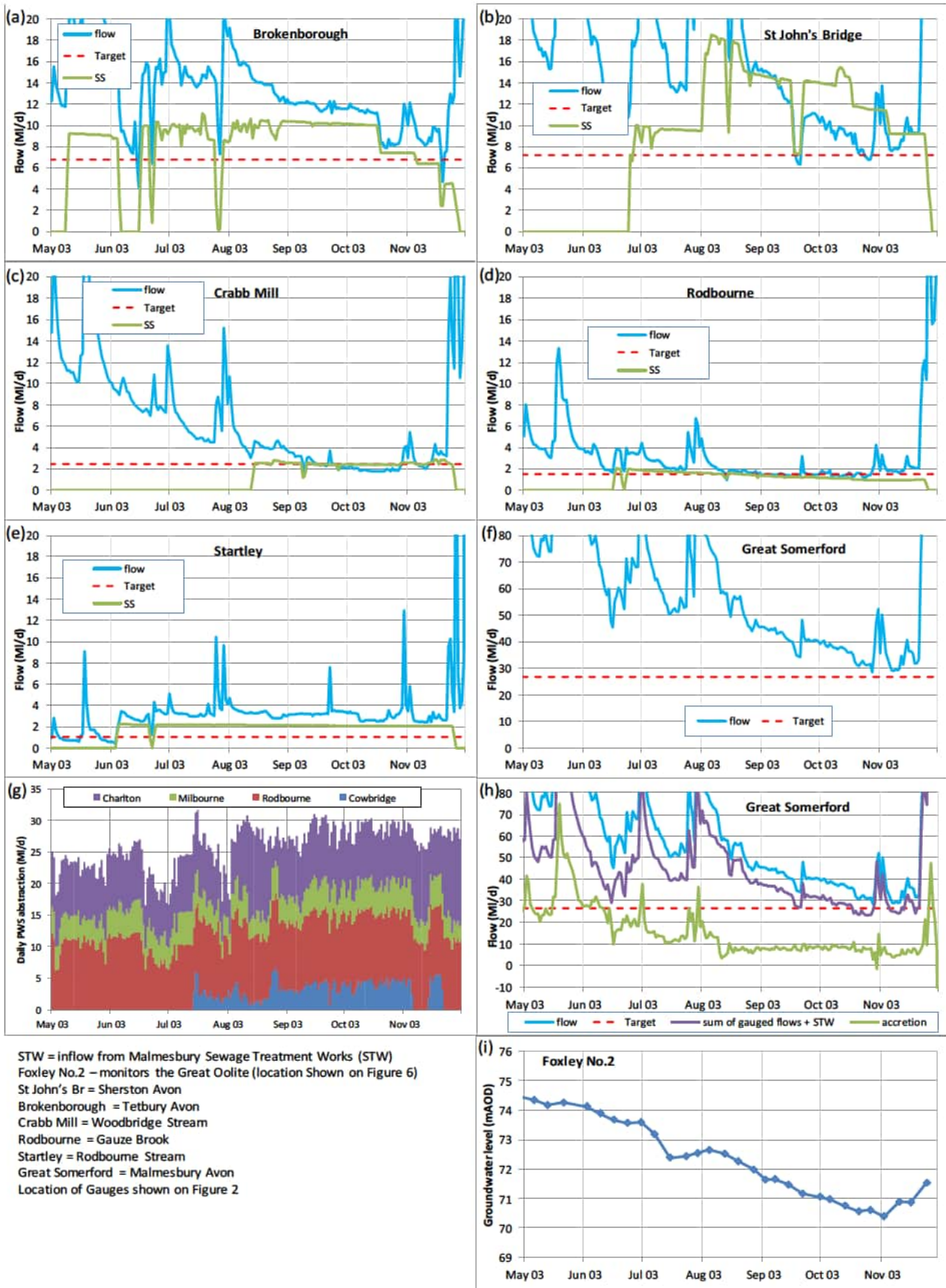


Figure 23: Malmesbury Avon and tributaries, gauged daily mean flow and upstream SS input (except for Great Somerford) (a-f), Wessex Water PWS sources daily volumes (g), Great Somerford flow, plus sum of upstream gauges (include STW inflow) and the difference between these flow, accretion (h) and Foxley No.2 groundwater level (Great Oolite) (i). All for the period May to November 2003.

Figure 23 (h) shows a recessing gain (accretion) from mid-May to mid-August, though rainfall events perturbate the overall picture. From mid-August the flow gain along this reach is 'constant' at ~8 MI/d. This is hard to explain, as the groundwater level in the Great Oolite aquifer, feeding the river, continues to decline (Figure 23 (i)). Also, in 2003 the Inferior Oolite SS signal test lowered the Inferior Oolite water level below the Great Oolite water level, such that the flow direction was from the Great Oolite to the Inferior Oolite, therefore, there was no potential for Inferior Oolite water to enter the river. In fact, the Great Oolite groundwater level at Cowbidge Obs, next to the Avon, was below ground level in Sep-Oct 2003, such that little or no Great Oolite water could enter the river.

The aquifers feeding the river continued to recess in 2003, such that a flow into the river becomes unlikely, but the river gains ~8 MI/d. A flow of this magnitude cannot be due to the minor aquifers, as their outcrop area is too small, plus a recession should still be seen. This pattern of a constant gain is seen in other years, notably in 2011, a particularly dry summer. In 2011, the gain is ~5-6 MI/d (Aug-Dec).

Data back to 1978 has been examined to see if this phenomenon is a new feature. In the absence of St John's Bridge data, Fosseway data has been used. Again, the upstream flow data have been summed and subtracted from the Great Somerford flow (no STW correction). The annual plots (April to Nov) for 1978 to 2016 are contained in Appendix I, with selected years shown on Figure 24. These plots for 'dry' years (1990, 1995, 2003 and 2011) show a flow change recessing to a constant value, near the zero line, and staying at this 'constant' value for several months. When the 'constant' value is reached, typically the groundwater level at Foxley is declining below 72 mAOD and in 1990, particularly, the groundwater level keeps on recessing.

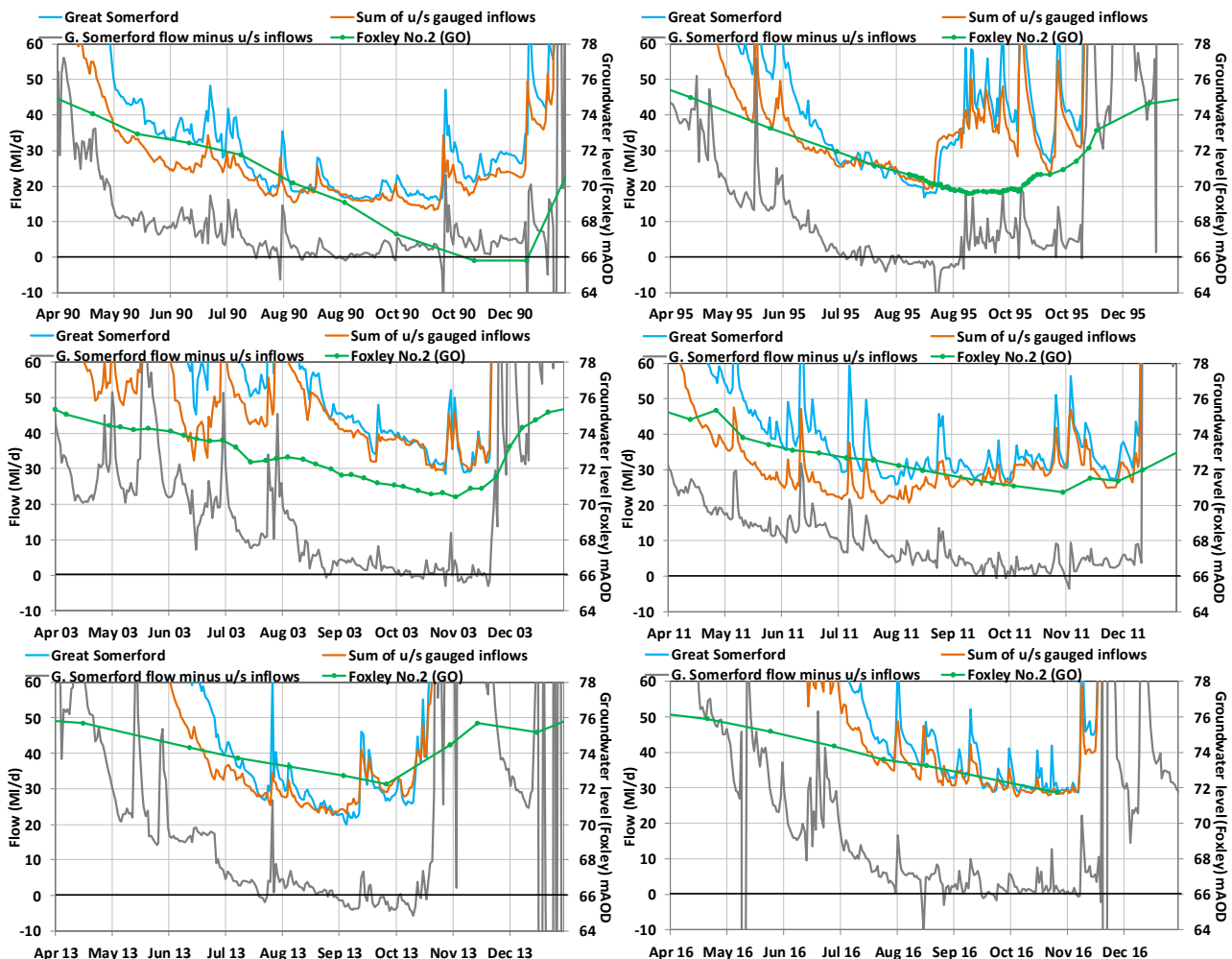


Figure 24: Malmesbury Avon daily mean flow: at Great Somerford, the sum of upstream gauges (Fosseway, Brokenborough, Crabb Mill, Rodbourne and Startley), the difference between these flows and the Foxley No.2 groundwater level (Great Oolite), for the period April to December, in 1990, 1995, 2003, 2011, 2013 and 2016

The data from 2013 is at variance to this pattern. In 2013, the data shows a loss of flow along the lower reach (Appendix I and Figure 24), even though the Foxley water level is >72 mAOD. A notable change in 2013, compared to 2003 and 2011, was that Cowbridge PWS was used all year at ~6.5 MI/d. The potential for this to alter the river flow behaviour has been examined. The groundwater levels at Foxley No.2 and Cowbridge Obs in 2003, 2011 and 2013 are shown on Figure 25. The Foxley data is indicative of the groundwater level across the catchment. Cowbridge Obs monitors groundwater level next to the Cowbridge source (~100 m away). The 2013 climate was 'wetter' than in 2003 and 2011, shown by the higher groundwater at Foxley in 2013, compared to 2003 and 2011. This same pattern is seen at Cowbridge (May, June and October, but a data gap through July to September means the actual water level at the critical time in 2013 cannot be directly compared).

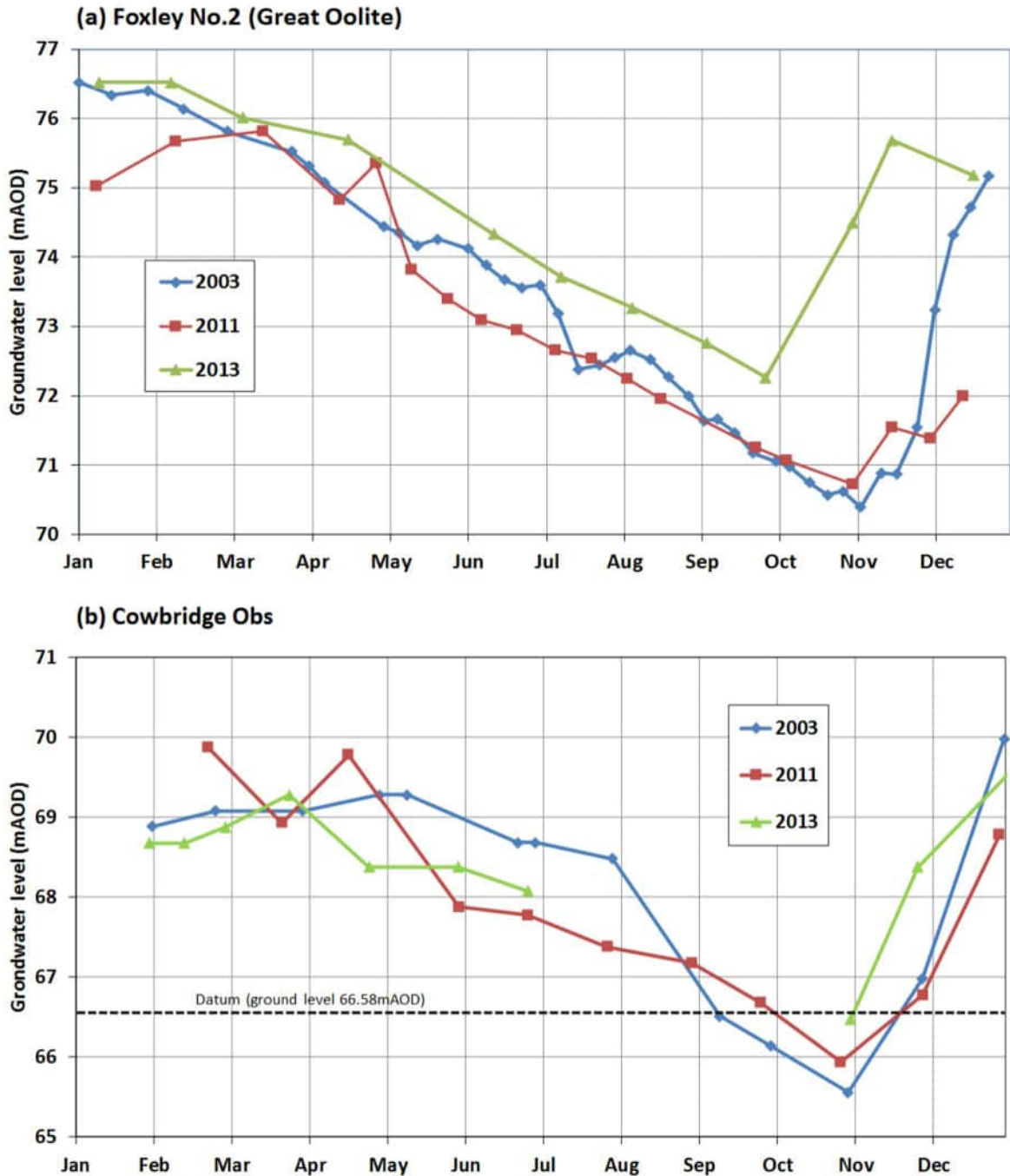


Figure 25: Great Oolite groundwater level hydrograph for (a) Foxley (No.2) and (b) Cowbridge in 2003, 2011 and 2013

In 2016 (Figure 24) a more consistent picture is seen, with a 'zero' gain when the Foxley level approaches 72 mAOD, even with Cowbridge abstracting 6 to 6.6 MI/d.

The different behaviour observed in 2013, led to trials being devised to define the impact of Cowbridge on this lower reach. The plan was to reduce and then increase abstraction at Cowbridge, at a range of groundwater levels, and monitor the resultant change in river flow, measured at St John's Bridge and Great Somerford. Unfortunately, 'wet' summers and operational concerns meant that successful trials could not be undertaken. Consequently, the influence of Cowbridge remains unresolved. Therefore, to allow this RSA scheme to be licensed Wessex Water has proposed to use Cowbridge as the 'source of last use' (Section 6.3.1) and in subsequent summers to undertake trials to define the Cowbridge impact. Trialling is now operationally feasible as concerns regarding turbidity have been resolved.

### **3.3.8 Location and rate of leakage**

As described, the PWS abstractions reduce and can, in certain years, eliminate the discharge of baseflow to the Malmesbury Avon upstream of Great Somerford. In addition to reducing baseflow to the river, if groundwater levels continue to decline the river becomes perched and leakage from the river can occur. Leakage has been identified along the Sherston Avon due to the PWS abstraction; the rate of leakage along this reach is examined in this section.

#### **Sherston Avon: Fosseway to St John's Bridge**

The change in river flow between the Environment Agency continuous gauging stations at Fosseway and St John's Bridge during 2003 is shown on Figure 26 (i), together with the daily mean flow at both flow gauging stations. Figure 26 (i) shows a gain in flow along this reach during January and February, but by mid March no gain in flow is observed. Figure 26 (ii) shows that between April and the end of July there is a loss of flow along this reach, except following storm events when a gain in flow is observed for a few days, which gives the scatter to the points. Between August and late November a loss of flow along this reach is always recorded. The loss during August through to November stabilises at an average rate of ~12 MI/d (range 8 to 14 MI/d).

A relationship exists between this rate of leakage and the Great Oolite groundwater level. The relationship between change of flow (leakage) and groundwater level recorded at Foxley No.2 is shown on Figure 26 (iii). Extra data, which helps to substantiate this relationship have been obtained by using data from the Arches Farm observation borehole, an Environment Agency borehole next to Sherston Avon in Malmesbury. A water level logger was installed in Arches Farm borehole in 2003, from which daily mean levels were determined. A strong relationship between Arches and Foxley No.2 was observed, ( $r^2 = 0.92$ ) and hence that relationship was used to predict Foxley water levels, as shown on Figure 26 (iii). An increase in leakage is observed as the groundwater level declines from 74.75 mAOD to 71.20 mAOD. Below 71.20 mAOD the leakage is 'constant' at ~12 MI/d.

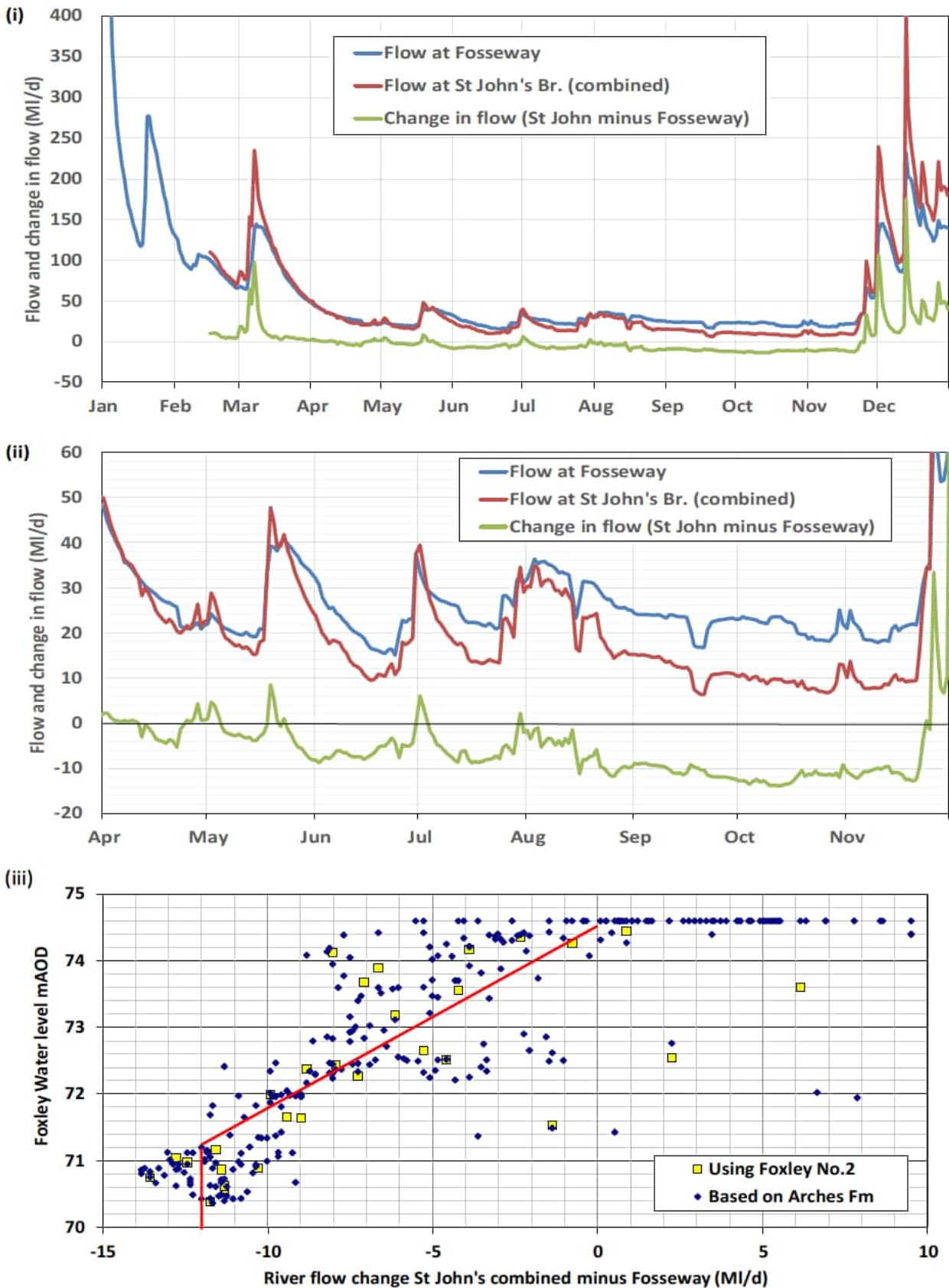


Figure 26: (i) Sherston Avon daily mean at Fosseway and St John's Bridge, plus the flow difference between these gauges, January to December 2003. (ii) as Chart 1, but for April to November 2003. (iii) the relationship between the flow change along the Sherston Avon (St John's Bridge minus the Fosseway flow) and the Foxley (No.2) water level (Great Oolite).

### 3.3.9 Summary of the effect of the PWS/SS abstractions on river flow

Wessex Water's PWS sources and Bristol Water's Shipton Moyne source are located near Malmesbury and draw water from the confined Great Oolite aquifer. Although confined, geological faults in the Malmesbury area allows the Great Oolite aquifer to discharge water (baseflow) to the River Avon. Groundwater from the Inferior Oolite contributes to this baseflow. The PWS abstractions reduce Great Oolite baseflow to the Malmesbury Avon and during a dry period, the flow can be stopped and the river becomes perched upstream of Great Somerford. Under these perched conditions flow in the Malmesbury Avon is provided by:

- Great Oolite fault controlled head water springs i.e. Crow Down Springs
- Forest Marble limestone baseflow (Sherston to Cowage Farm)
- Stream support discharges
- Sewage works discharges

## 3.4 How much stream support water is required?

The quantity of Inferior Oolite water from the SS boreholes at Luckington, Stanbridge and Tetbury required to maintain the RSol target flows along the Malmesbury Avon is considered in this section. The assessment approach is described in Sections 3.4.1 and 3.4.2 with the results from the assessment detailed in Section 3.4.3.

### 3.4.1 Assessment years

The Malmesbury Avon is sensitive to long periods of low rainfall, which results in naturally low flows. This behaviour is exacerbated by the PWS abstractions. As mentioned in Section 3.2, during the last 40 years, winter rainfall totals have been sufficient every year to suspend SS discharges and to allow the aquifer levels to recover. The Malmesbury Avon is therefore a single season critical catchment. The length of the low rainfall period in any one year will determine the amount of stream support that is required.

The naturalised (for Inferior Oolite stream support, including Hullavington) river flow at Great Somerford in notable dry years i.e. 1976, 1990, 1995, 2003 and 2011, are presented on Figure 27. The number of days in each year when the naturalised flow is below the prescribed flow is also shown on Figure 27. 1990 has the largest number of days with flow below the prescribed flow, totalling 168 days, compared to 100 days in 1976.

It is acknowledged that the Wessex Water PWS abstraction rate was much lower in 1976 and 1990, ~15 MI/d and 26.6 MI/d (as an annual average) respectively, so the impact in 1976 could have been greater. However, in 1976 Shipton Moyne/Long Newnton was abstracting at ~16 MI/d, and assuming at 55:45 ratio of take from each source (Section 2.6.2) and 50% of the Shipton Moyne water abstracted from the Great Oolite (Section 4.4.1), then the combined take from the Great Oolite by WW and BW in 1976 was ~20 MI/d, this is 15.4 MI/d less than the proposed licence. Assuming this extra take has a 1:1 impact on the flow at Great Somerford then the river recesses to the pf in late April 1976, increasing the days below the pf to 132 days.

In 1990, the Wessex Water PWS rate was ~26.6 MI/d, the Shipton Moyne/Long Newnton take was 13.5 MI/d, using the approach detailed above, the total Great Oolite total was ~30 MI/d, 5 MI/d lower than the proposed licence (35 MI/d). To address this extra need for SS if the Great Oolite source are operated at full licence, a 'Great Oolite model' has been developed. The development of this model and the results are presented in the next section.

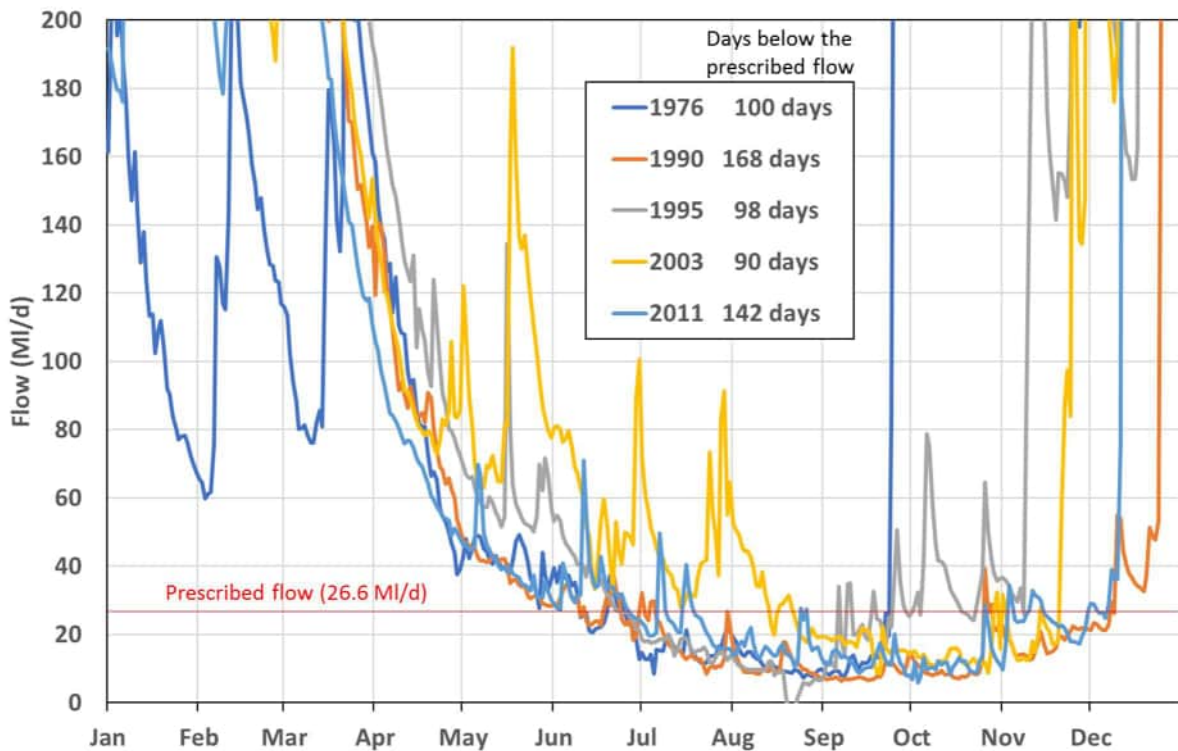


Figure 27: River Avon at Great Somerford: Naturalised for Inferior Oolite stream support: for selected years

In the Malmesbury Avon catchment 1990 was a climatically more severe year than 1976.

The available river flow data (Fosseway and Brokenborough) and groundwater level data (Foxley) allows the stream support requirements from Luckington, Stanbridge and Tetbury, to maintain the target river flows (Brokenborough and St John’s Br combined), to be calculated for the period 1978 to 2015. This includes the most critical year, 1990, plus the notable dry years of 1995 and 2011.

### 3.4.2 Assessment approach

The leakage regime along parts of the Malmesbury Avon detailed above have been used to determine the stream support requirement to meet target flows at St Johns Bridge, Abbey Weir and Great Somerford. The assessment is spreadsheet based (Stream Support calculator, ‘model’ value in Table 9) and the approach used is as follows:

#### St Johns Bridge

The assessment uses the historical groundwater level record at Foxley No.2 to determine the period and rate of leakage between Fosseway and St John’s Bridge. This approach has to be used as there is no St John’s Bridge data before 2003. Once the groundwater level recesses to 74.5 mAOD leakage starts and when it reaches 71.2 mAOD leakage is at the maximum rate of 12 MI/d. Between 74.5 and 71.2 mAOD the leakage rate is assumed to increase in a linear manner from 0 to 12 MI/d.

Leakage is subtracted from the naturalised (for historic Inferior Oolite SS input) flow at Fosseway to predict the flow at St John’s Bridge, if this flow is below the target flow (7.2 MI/d) then stream support water is added to achieve the target flow. The minimum pump rate is 2.5 MI/d, therefore, if the assessment calculates an input of less than 2.5 MI/d the value is defaulted to 2.5 MI/d. If the required stream support rate is greater than 2.5 MI/d, then this is rounded up to the nearest 0.25 and then 0.25 MI/d added. For example, if SS needed is 4.4 MI/d this becomes 4.75 MI/d. This ensures that a maintained flow is always 0.25 MI/d above the target flow. The pump arrangements allow the input to vary (up and down) in 0.25 MI/d steps.

Inspection of flow hydrographs shows that the flow trigger at Fosseway (14 MI/d) is reached ahead of the trigger/target at St John’s Bridge, so SS starts at 2.5 MI/d controlled by the Fosseway trigger.

## Audit

The assessment predicts the (modelled) flow at St John's Bridge to calculate the amount of stream support required to maintain the target. The St John's Bridge data is available post March 2003, so the assessment technique can be audited against actual flow to calculate the stream support requirement. The audit approach adds the amount of SS water required to the naturalised (for SS) St John's flow, to maintain the target flow – the theoretical value (calculated without reference to the Foxley water level). The actual, theoretical and modelled SS annual volumes for 2003 to 2015 are listed in Table 9.

The values in Table 9 show some good fits between the theoretical and modelled values e.g. 2003, 2004, 2009 and 2013. However, the fit in other years is poor, e.g. 2005 and 2011. These differences are attributed to two factors:

1. In the SS Calculator, the maximum stream bed leakage rate is 12 MI/d, based on 2003 field data. However, leakage rates were lower in 2005 and 2011 (Figure 28). Using the dashed red line to define the start and rate of leakage, and with a maximum leakage rate of 10 MI/d, the 2011 modelled SS volume reduces to 1276 MI/d.
2. The SS model uses the Foxley Great Oolite water level to predict stream bed leakage. In certain years the Foxley water level recesses, but the river flow can be 'held up'. This is due to rainfall events that result in run off and interflow from the Forest Marble/Cornbrash which leads to increased river flow, but these events do not cause a rebound in the Great Oolite water level. This is particularly evident in 2011 (Figure 29).

Table 9: Luckington and Stanbridge annual stream support totals to maintain target flow at St John's Bridge combined: actually used, theoretical and modelled (based on Foxley) (MI/a)

Year	Actual	Theoretical	Modelled <sup>1</sup>
2003	1889 <sup>2</sup>	1029	1031
2004	515 <sup>2</sup>	188	190
2005	523	436	770
2006	163	135	175
2007	72	20	20
2008	0	0	0
2009	503	429	451
2010	254	227	348
2011	1,435	1,265	1,860
2012	0	0	0
2013	535	411	461
2014	0	0	0
2015	691	440	575

<sup>1</sup> based on Foxley groundwater level and river leakage relationship (Figure 26)

<sup>2</sup> higher use in 2003 and 2004 than required to maintain flow targets due to trial pumping to define area affected by SS abstractions

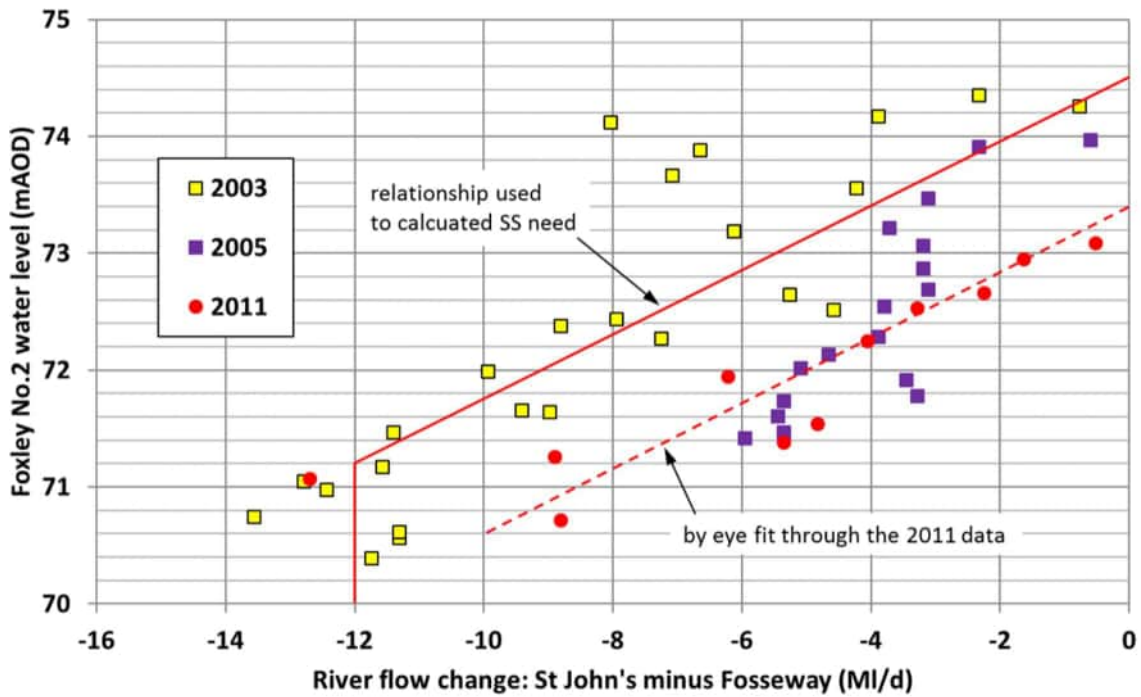


Figure 28: Sherston Avon stream bed leakage rates and Foxley No.2 water level relationship 2005 and 2011

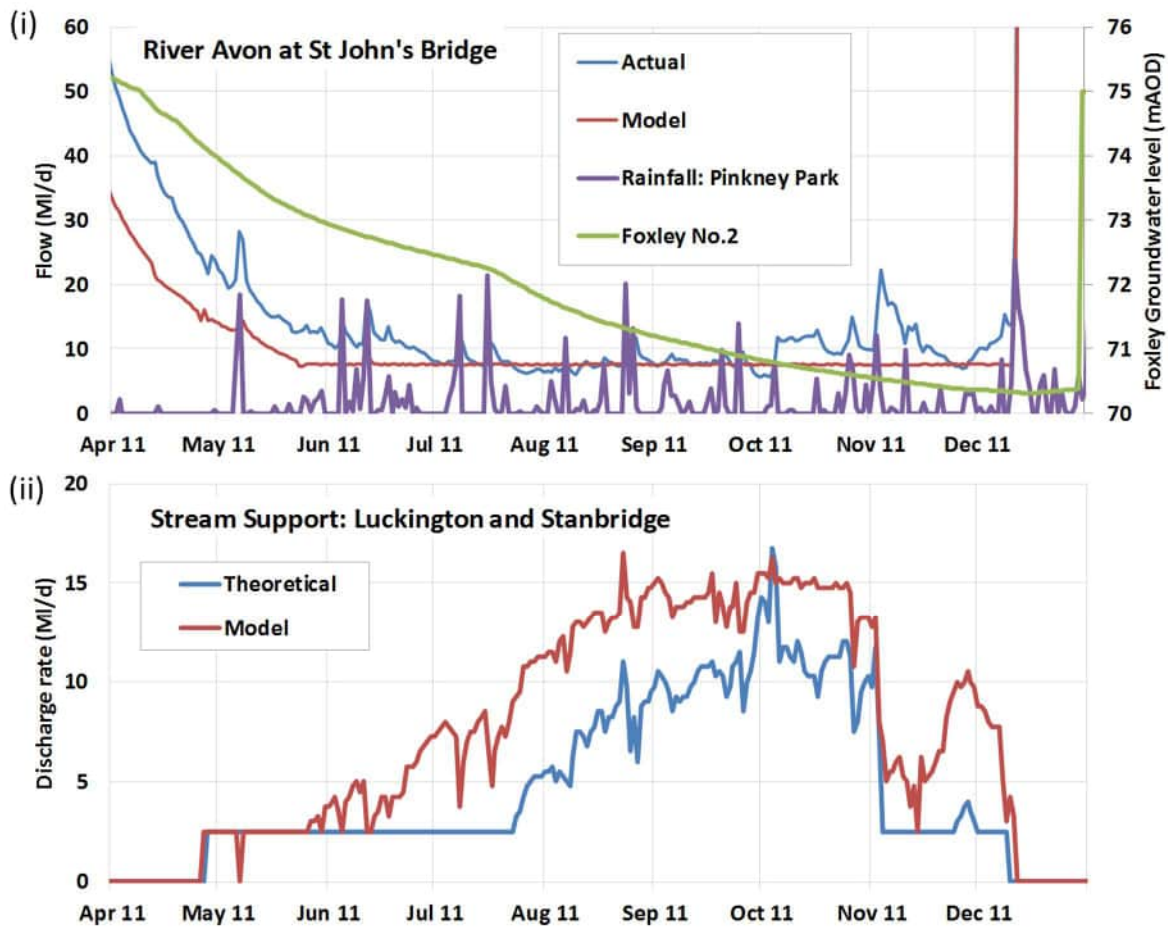


Figure 29: (i) River Avon at St John's Br (combined) actual and modelled, plus daily rainfall and Foxley No.2 groundwater level (ii) stream support rates (daily values) to maintain target flow at St John's Bridge: theoretical and modelled

Figure 29 shows the actual and modelled flow at St John's Bridge, together with the Foxley groundwater level (interpolated from monthly dips) and Pinkney Park daily rainfall, on the top chart (i) and the theoretical and modelled stream support rates on the bottom chart (ii). If the actual rate of river flow recession in April/early May 2011 ((i) blue line) had continued then in late May stream support would have increased above 2.5 MI/d (as modelled (ii)). However, rains in late May and a wet June (72 mm of rainfall, Pinkney Park) and storms in July held up the river flow such that SS above 2.5 MI/d was not needed after mid-July. Whereas, the modelling increased SS above 2.5 MI/d from late May based on Foxley.

In summary, the SS Calculator predicts the SS need in 'dry' conditions, but over predicts during 'wet' spells. However, this means the SS need in dry years i.e. 1990 and 1995 should be well predicted. The SS predictions in other years may well be overestimated, but this means the SS model is conservative in its overall predictions.

### Abbey Weir

There is no stream bed loss of flow along the Tetbury Avon, therefore, the naturalised (for historic stream support input) flow at Brokenborough is compared to the target flow for Brokenborough/Abbey Weir to determine the rate of stream support from Tetbury. As for St John's Bridge, the required input is rounded up to the nearest 0.25 and then 0.25 MI/d added. A minimum input of 2.5 MI/d is used.

### Malmesbury to Great Somerford

The situation along this reach is complex as detailed in Section 3.3.7. Except for 2013, since 1995 provided the target flows are being maintained at the upstream gauges the flow at Great Somerford has been compliant. As discussed in Section 3.3.7, residual concerns remain over the impact of Cowbridge and future trialling is proposed. Therefore, at this stage no additional SS from the Luckington, Stanbridge or Tetbury is assumed to be required to maintain the Great Somerford prescribed flow.

### Impact of maximum PWS use

The calculation of stream support need, described above, is based on historic river flows and groundwater levels, which are influenced by historic PWS abstraction. Therefore, the spreadsheet model predicts the stream support need based on historic levels of abstraction. However, these Wessex Water and BW PWS sources could operate at the proposed full licence rates, which would increase the rate of Great Oolite groundwater level recession and hence increase the need for stream support i.e. trigger SS to start earlier and operate at higher rates for longer.

Therefore, to quantify this extra SS need, a simplified model of the Great Oolite aquifer has been developed.

The model uses the relationship between the Great Oolite groundwater level (Foxley) and river flow (Great Somerford). The investigation tool is a spreadsheet based lumped water balance model which treats the Great Oolite as a single entity. Inputs (rainfall) and outputs (runoff, abstraction, baseflow and spring flow) are calculated over a five day period and groundwater level and river flow are predicted by the model. A report detailing the development of the model and its calibration is contained in Appendix J.

Given the relative simplicity of the model a reasonably good fit to river baseflow (Great Somerford) and groundwater levels (Foxley) is obtained, the groundwater calibration plot is shown on Figure 30. The model has been calibrated to simulate groundwater level recessions and hence river flow recessions. The model does not consistently replicate the speed of water level recovery, however, this is not considered to undermine its use during the key recession periods and times of low flow.

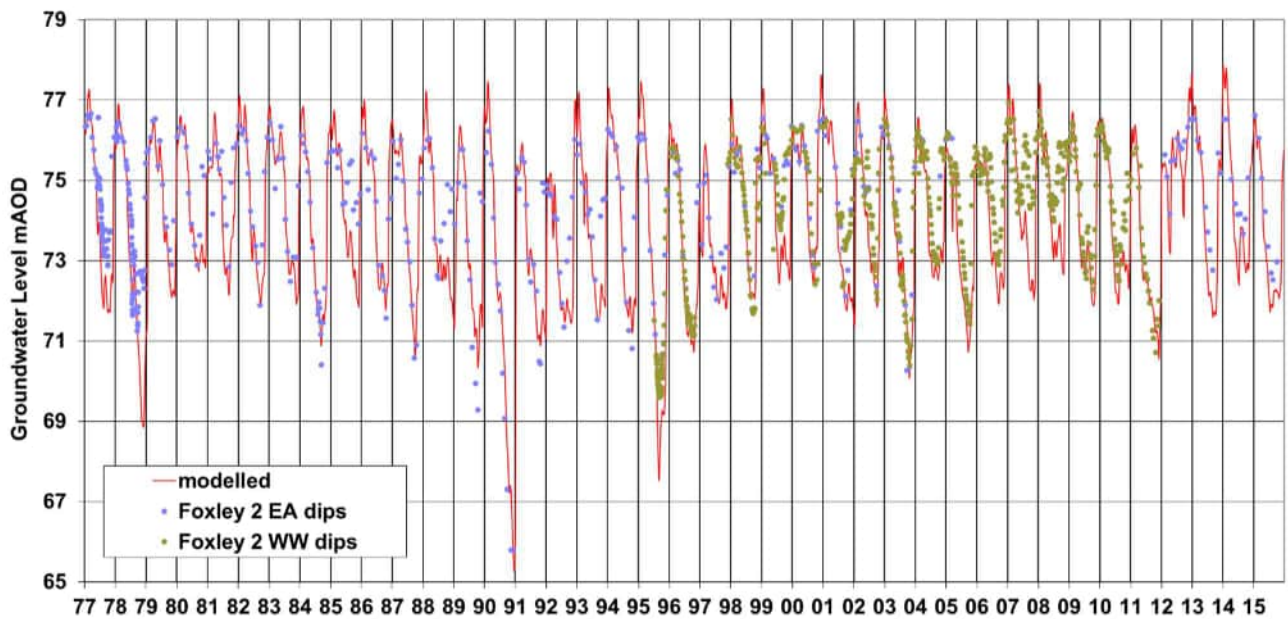


Figure 30: Great Oolite model – predicted and actual Foxley No.2 groundwater levels

The calibrated Great Oolite model was run to predict the Foxley groundwater level under historic PWS and full licence conditions (38 MI/d: Wessex Water PWS 35 MI/d and Bristol Water 3 MI/d (Shipton Moyne, see Section 4.4.1)). The resultant Foxley groundwater levels were subtracted from each other to define the extra drawdown due to full licence PWS use. On average (1978-2015) the extra drawdown is 0.40m. This extra drawdown was then taken off the observed Foxley groundwater level used in the Stream Support calculator (spreadsheet model) to predict the stream support need under full Great Oolite PWS use conditions. This approach is applicable to the Sherston Avon, but similar corrections are not possible for the Tetbury Avon, as there is no corresponding leakage relationship. The need for a Tetbury Avon correction is discussed in Section 3.4.3.

### Impact of Reduced PWS use

The Great Oolite model has also been used to assess the benefit of reducing the Great Oolite PWS to reduce the Inferior Oolite SS need. The restriction on Cowbridge use defined in the OA was designed to achieve this benefit. Therefore, a scenario has been run on the Great Oolite model whereby the full licence PWS rate (for Wessex Water) has been reduced from 35 to 27.5 MI/d. The predicted Foxley water level under the reduced full licence abstraction (27.5 MI/d), is then compared to historic abstraction. The average change is 0.08 m more drawdown under the reduced full licence abstraction scenario. This change in drawdown was then taken off the observed Foxley groundwater level used in the Stream Support calculator (spreadsheet model) to predict the stream support need under full Great Oolite PWS with a 7.5 MI/d reduction.

### 3.4.3 Results

The annual totals of Inferior Oolite SS required during 1978-2015, under (proposed) full PWS licence conditions, to maintain the target flows in Malmesbury, are shown on Figure 31. Summary statistics are presented in Table 10. The maximum is annual total occurs in 1990 totals 3742 MI. The inclusion of Hullavington SS, which abstracted 400 MI in 1990, gives a maximum annual total, from all four sources, of 4142 MI.

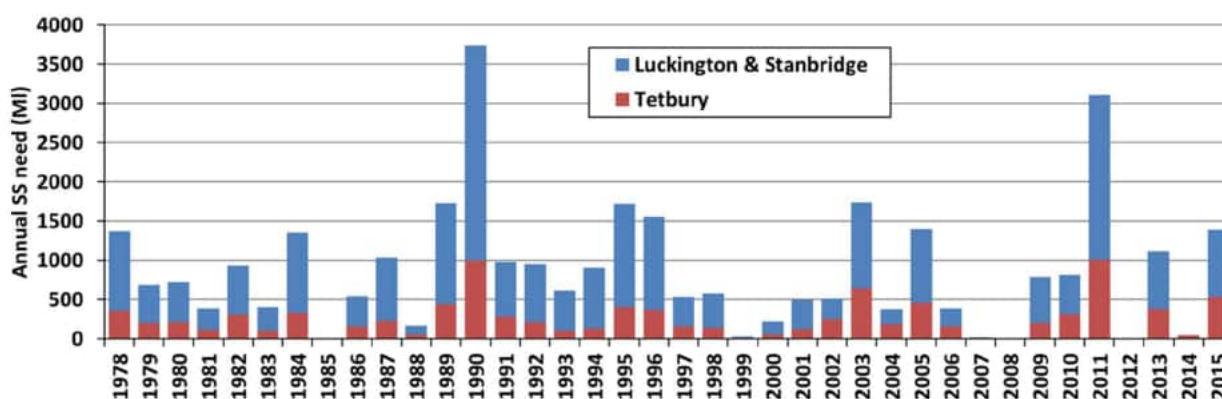


Figure 31 Predicted stream support requirement to maintain flow targets in Malmesbury with maximum use of Great Oolite PWS sources (proposed licences)

Table 10 Inferior Oolite stream support requirements - summary statistics to maintain flow targets in Malmesbury with maximum use of Great Oolite PWS sources (proposed licences)

Source	Average SS (1978-2015) MI/d	Maximum daily (MI)	Maximum Annual (MI)
Luckington	1.20	18	1,325 <sup>1</sup>
Stanbridge	0.50		1,416 <sup>1</sup>
Tetbury	0.70 <sup>2</sup>	7	1,001 <sup>1</sup>
<b>Total</b>	<b>2.40</b>	<b>25</b>	<b>3,742<sup>1</sup></b>

<sup>1</sup> the maximum annual use occurred in 1990

<sup>2</sup> based on historic PWS use

The SS calculator has also been run to define the need for SS under historic PWS conditions and this has been compared to the full Great Oolite proposed PWS licence SS need. For the Sherston Avon, full licence PWS use results in 0.28 MI/d of extra SS on average (1978-2015) and only 95 MI more SS in 1990, compared to SS need under historic PWS use conditions. Both scenarios have the same start date (1 May) in 1990, but the full licence use scenario results in the maximum river leakage rate occurring 12 days earlier. Consequently, the additional impact, compared to overall 1990 SS need from Luckington and Stanbridge is ~3.5% of the total.

The effect on the Tetbury Avon is, therefore, considered to be equally as small in 1990 (~35MI), and therefore a 'correction' has not been made. Overall, the long term (1978-2015) full Great Oolite PWS use results in 0.28 MI/d increase in SS need along the Sherston, 16% of the long term SS average. A similar increase might be expected, therefore, for the Tetbury Avon. A 16% increase in average SS from Tetbury equates to 0.11 MI/d. As a percentage of the average abstraction from the Inferior Oolite under the proposed licence (10.1 MI/d, Table 11), this increase represents ~1% of that total.

The potential impact of extra SS from Tetbury due to full licence Great Oolite PWS use is therefore small in 1990 and in the long term. As the impact is small and applying a correction is not possible for the full licence Great Oolite PWS use for Tetbury, such a correction has not been undertaken.

### PWS reduction

The benefit of the (Wessex Water) PWS reduction of 7.5 MI/d from 35 to 27.5 MI/d to reduce the SS need is small. Compared to the full licence impact, in 1990 SS started at the same time (1 May), but the maximum rate of leakage is reached 8 days later (16 July), which reduces the overall SS need by 62 MI (from 2742 to 2680). Based on the small net gain (62 MI) compared to the PWS reduction (577 MI: 1 May – 16 July), the PWS reduction was not considered sufficiently effective and the restriction on using Cowbridge for PWS was subsequently removed from the RSol.

## 4 Increasing Inferior Oolite stream support to maintain river flows

- A conceptual and calibrated numerical hydrogeological model of the Inferior Oolite and, hydraulically connected, Bridport Sand aquifers has been constructed.
- SS and PWS water is obtained from a hydraulically discrete compartment of Inferior Oolite.
- The Bridport Sand is fundamentally important to the high yields obtained from the Inferior Oolite SS boreholes. The Bridport Sand acts as a ‘reservoir’ and the Inferior Oolite collects and transmits the water to the boreholes.
- Empirical and numerical analysis has identified that 4142 MI can be abstracted from the SS boreholes to meet the river demand in a very dry year (equivalent to 1990).
- The use of the Inferior Oolite/Bridport Sand aquifer for SS is sustainable; there is no long-term decline in groundwater levels.
- One protected rights may be derogated by the use of SS boreholes to meet the high demand for SS, however, the use of a control curve will ensure this source is not derogated.
- The proposed overall level of Inferior Oolite abstraction is lower than currently licensed and hence streams draining the scarp edge will have higher flows.

### 4.1 Introduction

The assessment work detailed in Section 3 has identified that, under the proposed PWS licence variation, in a very long dry spring/summer/autumn (equivalent to 1990) the stream support demand to maintain target river flows in Malmesbury is 3742 MI (4142 MI, including Hullavington). In this section, the focus is on the sources where an increase in abstraction is proposed: Luckington, Stanbridge and Tetbury, though in the modelling assessment work presented the abstraction from Hullavington is included.

In this section, the following questions are addressed:

- Yield - Can the required yield for PWS and SS be obtained on a daily basis?
- Sustainability - Is the abstraction for PWS (Bristol Water) and stream support sustainable from the Inferior Oolite aquifer (long term impact on groundwater levels)?
- Impact - What is the impact of the short term (1990) and long term abstraction for PWS and SS on protected rights and the natural discharge points from the Inferior Oolite aquifer?

Empirical data from a pumping test in 2003 and the findings from numerical modelling are used to answer these questions. The development and result of the numerical model work is briefly presented in Section 4.2, and a full account is given in Appendix G. The questions regarding yield, sustainability and impact of the proposed abstraction are considered in Section 4.3 to 4.5. The residual environmental impacts of the Inferior Oolite stream support abstraction are detailed in Section 4.6.

### 4.2 Inferior Oolite – conceptual and numerical model

#### 4.2.1 Introduction

The model seeks to replicate the natural system, based on the understanding which has been developed (conceptualised) from the results and monitoring during the trials. The model is calibrated to the historical data and once a good match is achieved, the model can be used to predict the impact of the proposed abstraction regime under historic climatic conditions (1978 to 2015).

#### 4.2.2 Conceptualisation

Conceptual modelling involves reviewing and analysing geological, groundwater level, groundwater quality, aquifer parameter (transmissivity and storage), river flow, water balance (rate of water in and out of the aquifer) and meteorological data to determine:

- Boundaries to the aquifer
- How the aquifer is recharged (receives water)
- The flow direction and rate of flow within the aquifer
- Where the aquifer discharges water.
- The effect of abstraction

The conceptual understanding of the aquifer behaviour can be tested by construction of a numerical computer based model. The conceptual and numerical modelling is an iterative process, as results from the numerical modelling can change conceptual understanding. A report detailing the conceptual and numerical modelling work is contained in Appendix G.

The main points from the conceptualisation work undertaken for the Inferior Oolite aquifer are described below.

### **4.2.3 Aquifer boundary**

The Wessex Water operated SS boreholes and Bristol Water's sources abstract groundwater from a hydraulically discrete compartment of Inferior Oolite. The boundaries of this compartment are formed by the outcrop edge and geological faults, the boundary is shown on Figure 32. Hydrochemistry, permeability, groundwater contours and hydrograph data have identified the influence of the faults and allowed boundaries to the compartment to be defined where faulting is not mapped but the existence of faults is suspected.

The Inferior Oolite is hydraulically connected to the underlying Bridport Sand, together comprising the Lower Aquifer. The top and bottom of the Lower Aquifer are defined by the base of the Lower Fuller's Earth and top of Dyrham Silts respectively.

### **4.2.4 Aquifer properties**

The Inferior Oolite and Bridport Sand have contrasting aquifer properties. The Inferior Oolite has a high hydraulic conductivity (K - relative ease of water movement through the aquifer rock) compared to the Bridport Sand, whereas the Inferior Oolite storage values (Sy - quantity of water per unit block of drained saturated aquifer) is very low compared to the Bridport Sand value.

### **4.2.5 Recharge**

Potential recharge mechanisms to fill up the Inferior Oolite aquifer are shown on Figure 33. Analysis has identified that recharge of the Lower Aquifer occurs predominately via direct recharge over the outcrop area. Stream bed leakage into the Inferior Oolite along perched reaches of streams draining the Upper Aquifer along the scarp slope also form a significant inflow to the Lower Aquifer. However, the low permeability of the Lower Fuller's Earth and the findings from modelling (Appendix G) means diffuse leakage through this aquitard from the Great Oolite to the Inferior Oolite is a negligible component of the overall water balance.

### **4.2.6 Discharge**

The natural outflow points from the Lower Aquifer are scarp slope springs and upwards flow into the Great Oolite aquifer via faults through the Lower Fuller's Earth near Malmesbury. The Lower Aquifer compartment used for SS does not provide baseflow to the By Brook, therefore, these abstractions cannot impair flows in the Brook (Section 4.5.3).

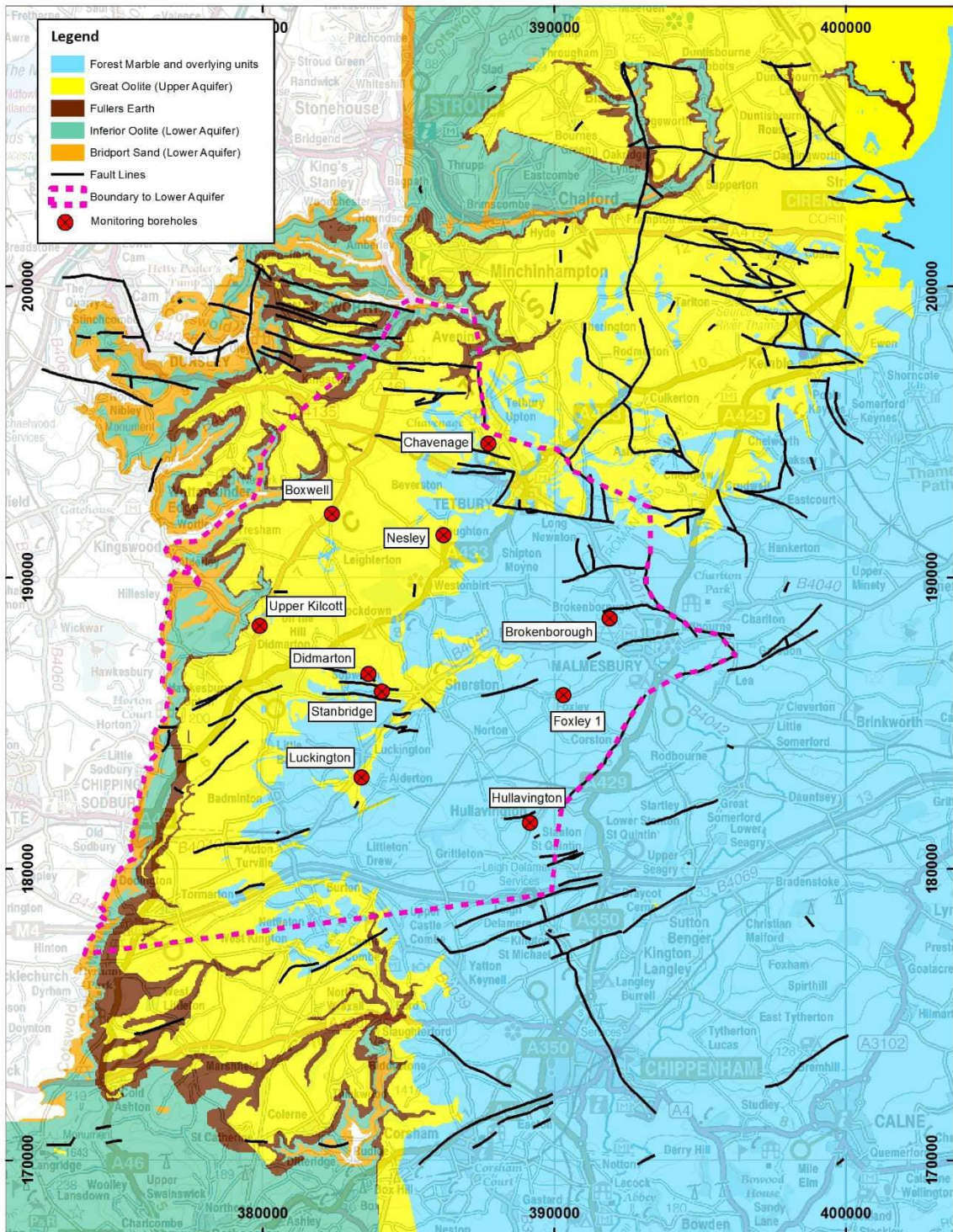


Figure 32 Boundaries to Lower Aquifer used for stream support

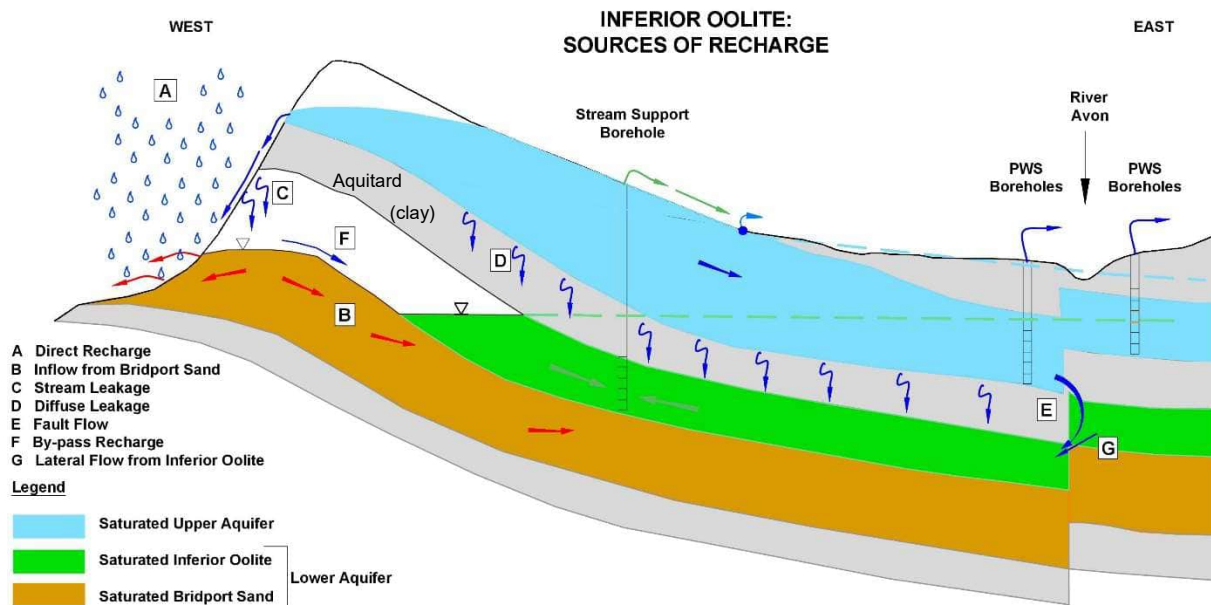


Figure 33 Sources of recharge to Lower Aquifer (schematic cross section)

#### 4.2.7 How the SS (& PWS) borehole yield is obtained

The Bridport Sand is fundamentally important to the successful yield obtained from the Inferior Oolite SS boreholes. The Lower Aquifer geometry and contrasting aquifer properties results in the Inferior Oolite water level being below the water level in the Bridport Sand when the SS boreholes are pumped (Figure 33). The head difference between the Lower Aquifer units means Bridport Sand water flows into the Inferior Oolite. In essence, the (low K / high Sy) Bridport Sand acts as a ‘reservoir’, and the (high K / low Sy) Inferior Oolite collects and transmits the water to the abstraction points. This allows yields of 10 MI/d from a single Inferior Oolite borehole, whereas the yield from a single Bridport Sand borehole would only be ~0.02 MI/d.

#### 4.2.8 Calibration

The model is initially constructed using the best estimate for the input parameters. The resultant output, groundwater level and spring flows, are compared to the available observed data to gauge the goodness of fit – the calibration. Within acceptable ranges the input values can be changed to improve the calibration, this is an iterative process. The final calibration from this process, comparison of modelled and observed groundwater levels, is shown on Figure 34. The overall calibration is considered to be good and therefore the model is viewed as ‘fit for purpose’. The purposes being to assess the sustainability of using the Lower Aquifer for increased SS (and lower PWS) and the impact of this abstraction on water features (scarp springs) and protected rights.

The model report (Appendix G) has been subject to an external review by Jane Dottridge, a Technical Director (Hydrogeology) at Mott MacDonalds, who states: ‘Overall it is concluded that a numerical groundwater flow model of the Malmesbury Lower Aquifer is now available, that is fit for the purposes required, i.e. to define the available Lower Aquifer water resources, assess the impact on the Lower Aquifer water levels of different PWS and SS abstraction profiles and assess the impact of the proposed solution on protected rights’. A copy of the review letter is contained in Appendix G.

Restoring Sustainable Abstraction – Malmesbury Avon

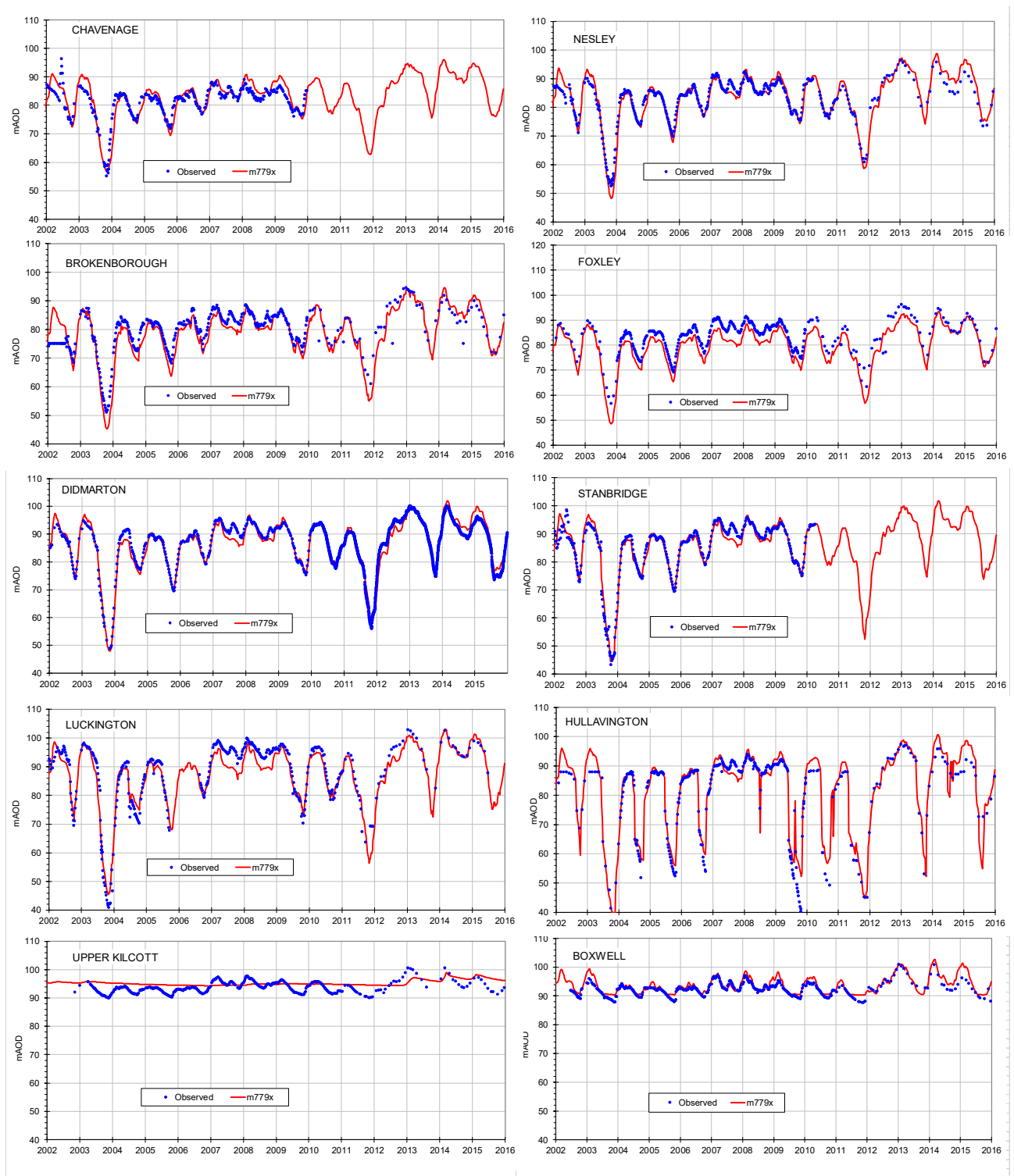


Figure 34 Lower Aquifer model m779x – calibration hydrographs

### 4.3 Is the required yield available?

During the 2003 pumping trial a total of 3548 MI was abstracted from the Inferior Oolite at Luckington, Stanbridge and Tetbury. The quantity abstracted in 2003 represents ~95% of the quantity needed in a repeat of 1990. Inspection of groundwater hydrographs from the 2003 trial (Marcus Hodges Environment, 2004) indicate that the remaining 5% could have been obtained. Therefore, the required maximum annual yield is available from the aquifer.

Test pumping has established that each borehole can provide 10 MI/d (Wessex Water, 2004b; 2004c). During the 2003 test the combined output from the three source boreholes totalled 28 MI/d in early August. The assessment work in Section 3.4.3 predicted a maximum daily need of 25 MI/d; the source boreholes can deliver this.

In summary, the required daily and annual yield to maintain flows in 1990 can be provided by the Inferior Oolite boreholes at Luckington, Stanbridge and Tetbury.

### 4.4 Sustainability

Sustainability addresses whether the Lower Aquifer (available resource) can meet the stream support demand year on year. The resource needs to be available every year if required. The numerical model is used to predict long term aquifer water level by assessing the impact of full licence use of the PWS source and the stream support need to maintain acceptable river flows.

#### 4.4.1 Scenarios modelled

The modelled scenarios cover the period 1978 to 2015 (38 years). Over this period, the historical climate record is used. The storage value of the Bridport Sand means that the effects of abstraction are temporally spread (buffering the impact), which means that the effect of a new abstraction regime can take several years to be fully realised from the start of the model run. Therefore, to take account of the need to allow 'storage' to equilibrate, the 1978 to 2015 runs have been repeated four times. The heads for end of Run 1 are used as the starting heads for the second run (2016 to 2034). The heads at the end of Run 2, are used as the starting heads for Run 3 and so on. Therefore, each model scenario covers a period of 152 years. As the climate is repeated over this 152 year period there are four 1990s etc.

The following scenarios have been run (the *mXXX*, refers to model run reference code):

#### ***Natural (m807)***

In this scenario no abstraction occurs. Sources of water into the Lower Aquifer are outcrop recharge and stream bed leakage over perched stream bed reaches. Outflow from the Lower Aquifer occurs via springs along the outcrop edge and via fault flow to the overlying Great Oolite aquifer.

#### ***Current abstraction licences (m808)***

The rates of abstraction required by the current licences are used in this scenario.

The stream support need is calculated to maintain the flow target detailed in Section 3.4.2, though the current licence pfs are used. Under the current licence the maximum abstraction rate from each source is 2.5 MI/d. Over the period 1978 to 2015 the average SS rates are listed in Table 11, though in the modelling the rates of SS vary, depending of the rate needed to maintain the pf.

The current Bristol Water licence allows a combined abstraction of 18.1 MI/d from Long Newnton and Shipton Moyne. Examination of the historic use of these sources shows that Long Newnton provides ~6 MI/d, so this rate has been used in this scenario (Table 11). The remaining 12.1 MI/d is applied to Shipton Moyne, however, this source is constructed to draw water from the both the Upper and Lower Aquifer (Section 2.6). The long standing assumption is that 50% of yield is obtained from the Inferior Oolite, so 6.05 MI/d is assigned to the Lower Aquifer.

Tetbury licence of 1200 MI/a is applied as a daily average of 3.29 MI/d.

The abstraction rates from licensed private source are included in this scenario.

Table 11 Model scenario abstraction rates applied (all values in MI/d)

Scenario		Current licence (m808)	Proposed licences - A (m809)	Proposed licences - B (m810)
PWS	Tetbury	3.29	2.20	2.20
	Long Newton	6.00	1.59	1.59
	Shipton Moyne	6.05	3.00	4.76
	<b>Sub Total</b>	<b>15.34</b>	<b>6.79</b>	<b>8.55</b>
SS <sup>1</sup>	Hullavington	0.48	0.48	0.48
	Luckington	0.28	1.20	1.20
	Stanbridge	0.11	0.50	0.50
	Tetbury	0.52	0.70	0.70
	<b>Sub Total</b>	<b>1.39</b>	<b>2.88</b>	<b>2.88</b>
Private supplies	All	0.43	0.43	0.43
<b>Combined total</b>		<b>17.16</b>	<b>10.10</b>	<b>11.86</b>

<sup>1</sup> The rates of SS use vary on a daily basis, so to provide a value to allow the SS use to be compared to other abstractors the SS values shown are the long term averages (1978-2015).

#### **Proposed abstraction licences (m809)**

The rates of abstraction that would occur under the proposed licences (Bristol Water and Wessex Water) are used in this scenario. The abstraction rates applied in this scenario are summarised in Table 11.

The approach detailed in Section 3.4 has been used to determine the stream support need to maintain the new river flow targets.

The proposed Bristol Water licence change will see all three sources within a group licence, with a daily limit of 12.1 MI/d and annual total of 3573 MI, equivalent to a daily average of 9.79 MI/d. This is 1.5 MI/d lower than the MoU values, because to address a long term sustainability issue Bristol Water agreed to a further 1.5 MI/d reduction, with Wessex Water making a commensurate reduction in the water it imports from BW to maintain BW's supply-demand balance.

Tetbury source supplies the local town at a typical recent rate of 2.2 MI/d, this rate is used in the scenario.

For the Shipton Moyne and Long Newton sources, Shipton Moyne will be the primary source of supply so 6 MI/d has been assigned to this source, again assuming 50% is obtained from the Inferior Oolite a daily abstraction of 3 MI/d is assigned. The residual 1.59 MI/d (9.79 – 2.2 – 6) is assigned to Long Newton.

The abstraction rates from licensed private sources are included in this scenario.

Compared to current licence arrangement, this scenario results in a net reduction in licensed abstraction of 7.06 MI/d, a 41% reduction.

### ***Proposed abstraction licences (m810)***

This scenario is a more precautionary version of m809 detailed above, designed to address the uncertainty over the proportion of the Shipton Moyne yield derived from the Inferior Oolite. In this scenario, more of the Shipton Moyne abstraction is assigned to the Inferior Oolite aquifer. The following is assumed: during the winter (Dec – April) 50% of the yield (6 MI/d) is from the Inferior Oolite, whereas from May to November all the yield is assumed to be from the Inferior Oolite. This leads to annual abstraction from the Inferior Oolite at Shipton Moyne of 4.76 MI/d. This representation also effectively addresses a situation where Shipton Moyne cannot be used, and Long Newnton becomes the primary source of supply.

## **4.5 Impact**

The potential impacts of increasing SS on the discharge areas for the Inferior Oolite/Bridport Sand aquifer are examined in this section. There are three discharge areas, identified by the hydrogeological conceptual model, to be considered, plus protected rights:

- Great Oolite aquifer and River Avon
- Cotswold scarp slope springs and streams
- By Brook
- Protected rights

The output from the natural, current licence and proposed licence scenarios are summarised in Figure 35, which shows the water balance from these model runs. These outputs are examined the following sections.

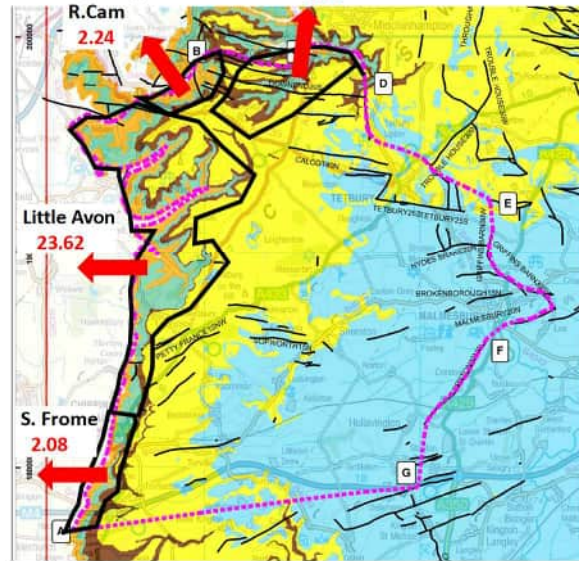
Restoring Sustainable Abstraction – Malmesbury Avon

Lower Aquifer\* Water Balance: Long term average (38 years: 1978 (2092) to 2015 (2129))

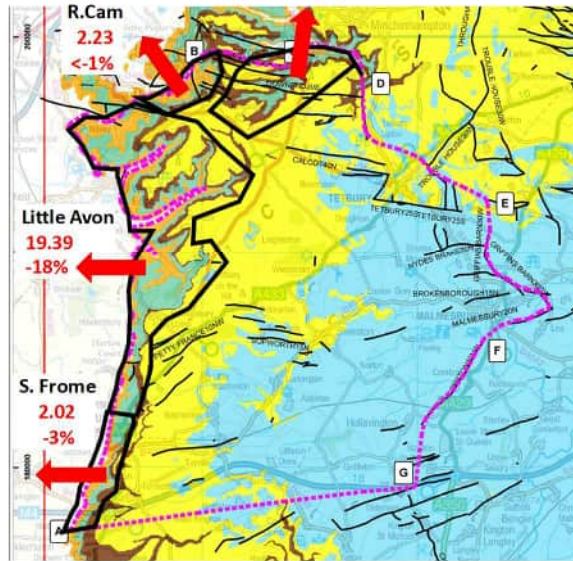
\*Lower Aquifer : Bridport Sand and Inferior Oolite

Units MI/d

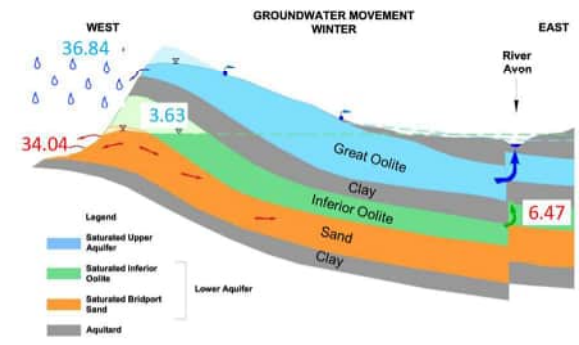
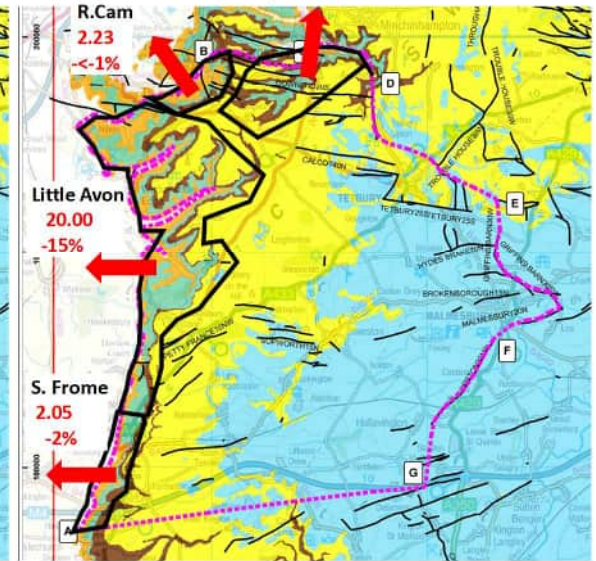
Natural (m807)



Current Full licence (m808)

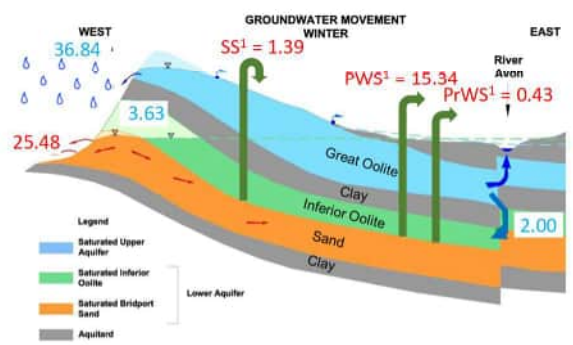


Proposed Full Licence (m809)



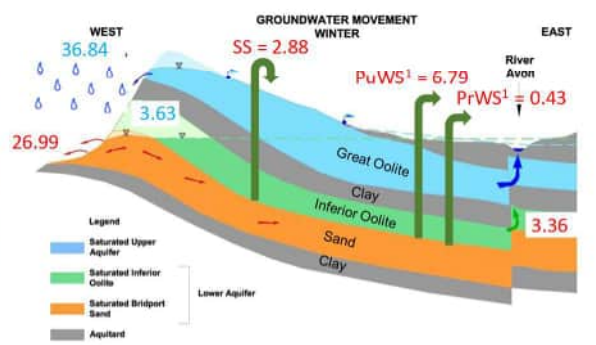
m807

$$\begin{aligned} \text{IN} &= \text{OUT} \\ \text{recharge} + \text{bed leakage} &= \text{spring flow} + \text{fault flow} \\ 36.84 + 3.63 &= 34.04 + 6.47 \\ 40.47 &= 40.51 \end{aligned}$$



m808

$$\begin{aligned} \text{IN} &= \text{OUT} \\ \text{recharge} + \text{bed leakage} + \text{fault flow} &= \text{spring flow} + \text{abstraction}^1 \\ 36.84 + 3.63 + 2.00 &= 25.48 + 17.16 \\ 42.47 &= 42.64 \end{aligned}$$



m809

$$\begin{aligned} \text{IN} &= \text{OUT} \\ \text{recharge} + \text{bed leakage} &= \text{spring} + \text{fault flow} + \text{Abstraction} \\ 36.84 + 3.63 &= 26.99 + 3.36 + 10.11 \\ 40.47 &= 40.47 \end{aligned}$$

Figure 35 Lower Aquifer modelled water balance (1978-2015: 38 years): Natural, current licence and proposed licence conditions

### 4.5.1 Great Oolite aquifer and River Avon

The rate of flow from the Lower Aquifer to the Great Oolite aquifer is dependent on the head difference between the aquifers and the permeability of the connecting strata. The numerical modelling results indicate that naturally the average flow to the Great Oolite is ~6.5 MI/d, ranging from 5.57 and 7.82 MI/d. This water will form part of the baseflow to the River Avon.

The abstractions from the Lower Aquifer reduce this outflow and during prolonged use the flow is stopped and reversed i.e. Great Oolite water flows into the Lower Aquifer. Under the current licence arrangement, the model predicts an almost continual flow reversal with an average flow of ~2 MI/d (range -5.1 to 0.15 MI/d) of flow from the Great Oolite to Lower Aquifer.

Under the proposed licence arrangement (m809), the average flow direction is back to being from the Lower to the Upper aquifer. The average from the Lower Aquifer to the Great Oolite is 3.36 MI/d (a 3.14 MI/d reduction compared to the natural situation), the range is -1.89 (Great Oolite to Lower Aquifer) to 5.41 MI/d. The reversal of flow occurs in 1990 and 2011, see Figure 36.

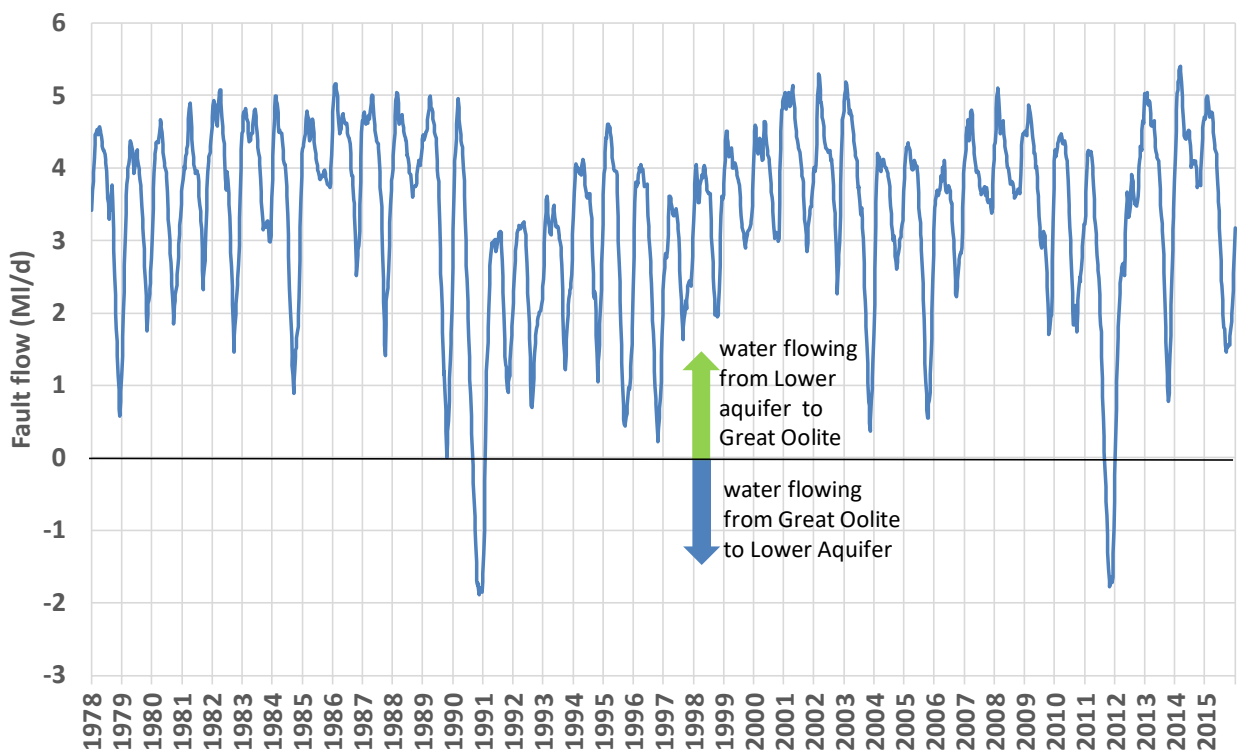


Figure 36 Proposed licence scenario (m809) modelled fault flow

Therefore, the PWS and SS abstractions, reduce the flow to the Great Oolite aquifer and hence the Malmesbury Avon. However, in relation to the SS component of this reduced outflow, it is not considered to be a significant issue for the following reasons;

- The Inferior Oolite SS water is added to the river that it was going to naturally discharge to anyway, in addition the SS water supports the whole river not just the river reach around and below Malmesbury which the natural discharge supports;
- During the autumn and winter (when SS is off) the Inferior Oolite flow contribution to the Great Oolite and hence Malmesbury Avon is reduced, as recharge to the Inferior Oolite will be replenishing the aquifer storage used during the summer. However, this loss (~3-5 MI/d) is small compared to the flows in the Malmesbury Avon (typically >100 MI/d) following the onset of winter recharge.

#### 4.5.2 Scarp slope springs and streams

As described in Section 4.2 the Inferior Oolite SS abstractions are supported by storage release from the Bridport Sand. The SS abstractions and PWS abstractions, therefore, reduce the amount of water that could discharge to the springs and streams that drain the Bridport Sand and Inferior Oolite along the scarp slope. Although this potential exists, no discernible impact on spring flows or Bridport Sand groundwater levels occurred during the 2003 pumping trial (Appendix G). The impact was not discernible because the relatively large specific yield value (20%) of the Bridport Sand 'buffers' the pumping impact, dissipating the impact over a longer time frame than just when the SS abstractions are active.

The modelled spring outflows (each drain cell) has been grouped depending on which catchment they feed. The groupings are shown in Figure 35; moving south to north these feed: South Frome (tributary of the Bristol Avon), Little Avon, River Cam and North Frome (Tributary of the River Frome). The 'buffering' effect is examined in Figure 37.

Figure 37 shows the modelled stream flow for the Little Avon and North Frome. South Frome and the River Cam are not presented as the abstraction impact on these streams is negligible. The modelled stream flows for the 'low' flow period of 1989 to 1995 are presented in Figure 37. On each plot the PWS and SS abstraction rates (as a cumulative plot) are shown for the corresponding period. The charts show no change in the rate of recession with the onset of stream support, even in 1990 when the SS pressure is at its greatest. The predicted natural flow is also plotted in Figure 37.

It is noted that post 1990, the impacted river (m809) flows recessed to lower flows in 1991 and 1992, suggesting a legacy from the 1990 use. However, the natural hydrograph (m807) also shows lower flows in 1991 and 1992, compared to 1990. These lower flows, post 1990 in runs m807 and m809, are due to relatively low recharge totals during the 1990/91 and 1991/92 winters.

The modelled outflows have been analysed to give the average outflow and 95 percentile (Q95) flow under natural, current licence and the proposed licence arrangements. The resultant average flows are shown in Figure 35 and presented in Table 12 together with the percentage flow change from natural for the licence scenarios. Table 12 also shows the Q95 flows and percentage change values. The Inferior Oolite is not the only source of flow to these streams. Groundwater flow inputs occur from the Upper Fuller's Earth, and areas of Lower Aquifer not within the (Malmesbury) component used for PWS and SS.

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Table 12 Lower Aquifer modelled average (1978-2015) daily outflows and Q95 flows under natural, current licence<sup>1</sup> and proposed licence<sup>1</sup> conditions

Outflow location	Scenario	Average flow (MI/d)	Change from average Natural (MI/d)	Change from average Natural flow as % of natural flow	Q95 flow (MI/d)	Change from Natural Q95 (MI/d)	Change from Natural Q95 as % of Natural Q95
South Frome	Natural	2.08	-	-	1.23	-	-
	Current full licence	2.02	-0.06	-3	1.18	-0.05	-4.1
	Proposed full licence	2.05	-0.03	-2	1.20	-0.03	-2.5
Little Avon	Natural	23.62	-	-	14.48	-	-
	Current full licence	19.39	-4.23	-18	12.4	-2.07	-14.3
	Proposed full licence	20.0	-3.62	-15	12.72		-12.2
River Cam	Natural	2.24	-	-	1.46	-	-
	Current full licence	2.23	-0.01	<-1	1.45		<-1
	Proposed full licence	2.23	-0.01	<-1	1.45		<-1
North Frome	Natural	6.10	-	-	4.00	-	-
	Current full licence	1.84	-4.26	-70	0.99		-75
	Proposed full licence	2.71	-3.39	-56	1.43		-64
Fault flow	Natural	6.47	-	-	-	-	-
	Current full licence	-2.00	-8.47	-131	-	-	-
	Proposed full licence	3.36	-3.11	-48	-	-	-

<sup>1</sup> the SS rates vary temporally in the scenarios to maintain river flows

The impact of Inferior Oolite abstractions on the flow from these scarp slope springs and streams is not new, as the impacts from PWS abstractions have been occurring for over seven decades. The proposed licence changes will result in less abstraction, compared to the current licensed arrangements. Therefore, the flow in these streams will be greater than historical flows, though the increase may not be readily noticeable as the proposed licence changes have effectively been in place since 1999.

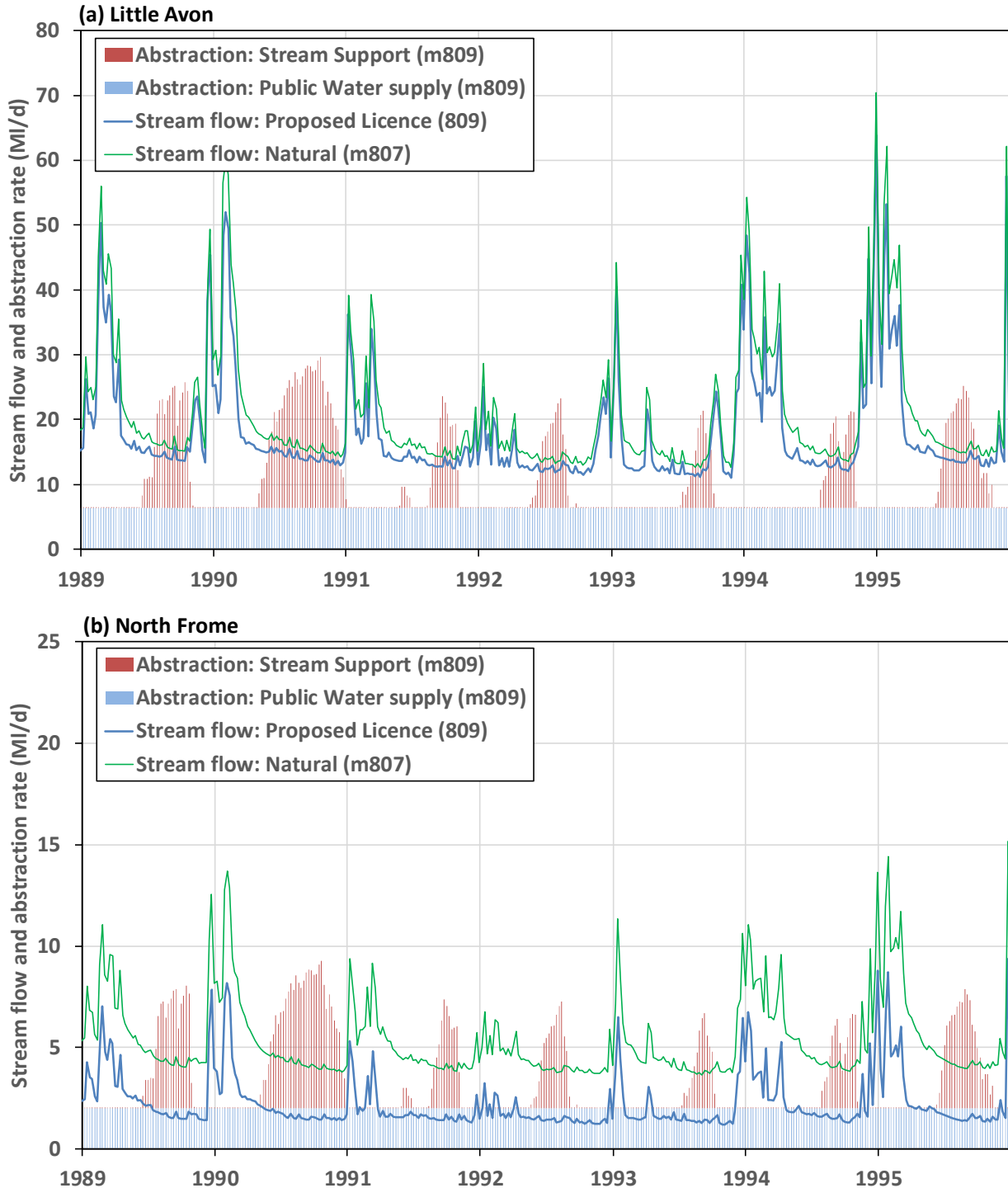


Figure 37 Modelled stream flows (Natural m807 and under the proposed licence m809): Little Avon and North Frome

### 4.5.3 By Brook

#### Introduction

The By Brook is located to the south of the Malmesbury Avon catchment (Figure 2). A review at the start of the Sol period identified that SS abstractions could potentially reduce flow in the By Brook. Concern that flows in the By Brook are impacted by the increased SS abstraction were heightened by observations from a local environment group (Friends of the By Brook) who reported that flows in the By Brook (upstream of Ford) are lower than historically. Consequently, focused investigations were undertaken to determine whether flow in the By Brook is reduced by the Inferior Oolite stream support abstractions.

In this section, the mechanisms that could impact By Brook flow are described and then the potential for each mechanism to cause an impact is examined. Concurrent work by the Environment Agency related to a Restoring Sustainable Abstraction study of By Brook is also presented. Firstly, a brief description of the By Brook catchment geology, hydrology and location of key features is given.

#### Geology and hydrology

A simplified outcrop geology map of the By Brook upstream of the Lid Brook is shown on Figure 38. Figure 38 also shows spot gauging locations along the By Brook and its tributaries that Wessex Water have been measuring either routinely (weekly/fortnightly) since June 2003 or as part of shorter term focussed studies.

The summer perennial head of the brook is located just north of Point 11 at Goulter's Mill, close to the mapped boundary of the Great Oolite and Upper Fuller's Earth. In the winter the Brook starts flowing near the A46, giving a winterbourne reach of ~6km. Upstream of Ford the brook and its tributaries drain the Great Oolite aquifer and limestones within the Upper Fuller's Earth. Downstream of Ford, the brook receives additional inflows from the Inferior Oolite and Bridport Sand aquifers.

#### Mechanisms

Assessment work has identified two mechanisms by which SS abstractions could potentially reduce flow in the By Brook. Figure 39 shows the two mechanisms operating to reduce brook flow along a schematic geological cross-section between the Malmesbury Avon and By Brook catchments. The line of section is shown in Figure 38. How each mechanism could operate to potentially reduce flow in the By Brook is described below.

#### Mechanism A

Within the By Brook and Malmesbury Avon catchments the lowest topographic elevation of outcropping Inferior Oolite occurs at Ford. Consequently, it is expected that a major outflow of Inferior Oolite groundwater would occur at Ford. If the Inferior Oolite outcrop at Ford is hydraulically connected to the Inferior Oolite used for SS in the Malmesbury Avon catchment, as depicted on Figure 39, then the SS abstractions would reduce the Inferior Oolite outflow at Ford and hence reduce the brook flow.

#### Mechanism B

Groundwater levels in the Great Oolite are at a higher elevation than the water levels in the Inferior Oolite. These two aquifers are separated by the Lower Fuller's Earth. The water level difference provides the potential for water to flow from the Great Oolite to the Inferior Oolite aquifers. The amount of flow between the aquifers is dependent on the magnitude of the water level difference and permeability of the Lower Fuller's Earth. The pumping for SS increases the water level difference and hence increases the flow from the Great Oolite to the Inferior Oolite aquifer. Consequently, this reduces the volume of water in the Great Oolite aquifer. Pumping for SS therefore could reduce the outflows from the perennial springs that drain the Great Oolite aquifer at the top of the By Brook.

#### Impact assessment: intercepting aquifer throughflow (Mechanism A)

This mechanism assumes that the abstraction from the Inferior Oolite beneath the Malmesbury Avon catchment reduces the discharge to the By Brook from the Inferior Oolite where it outcrops in the By Brook valley floor, just south of Ford. Evidence for such an impact is now considered.

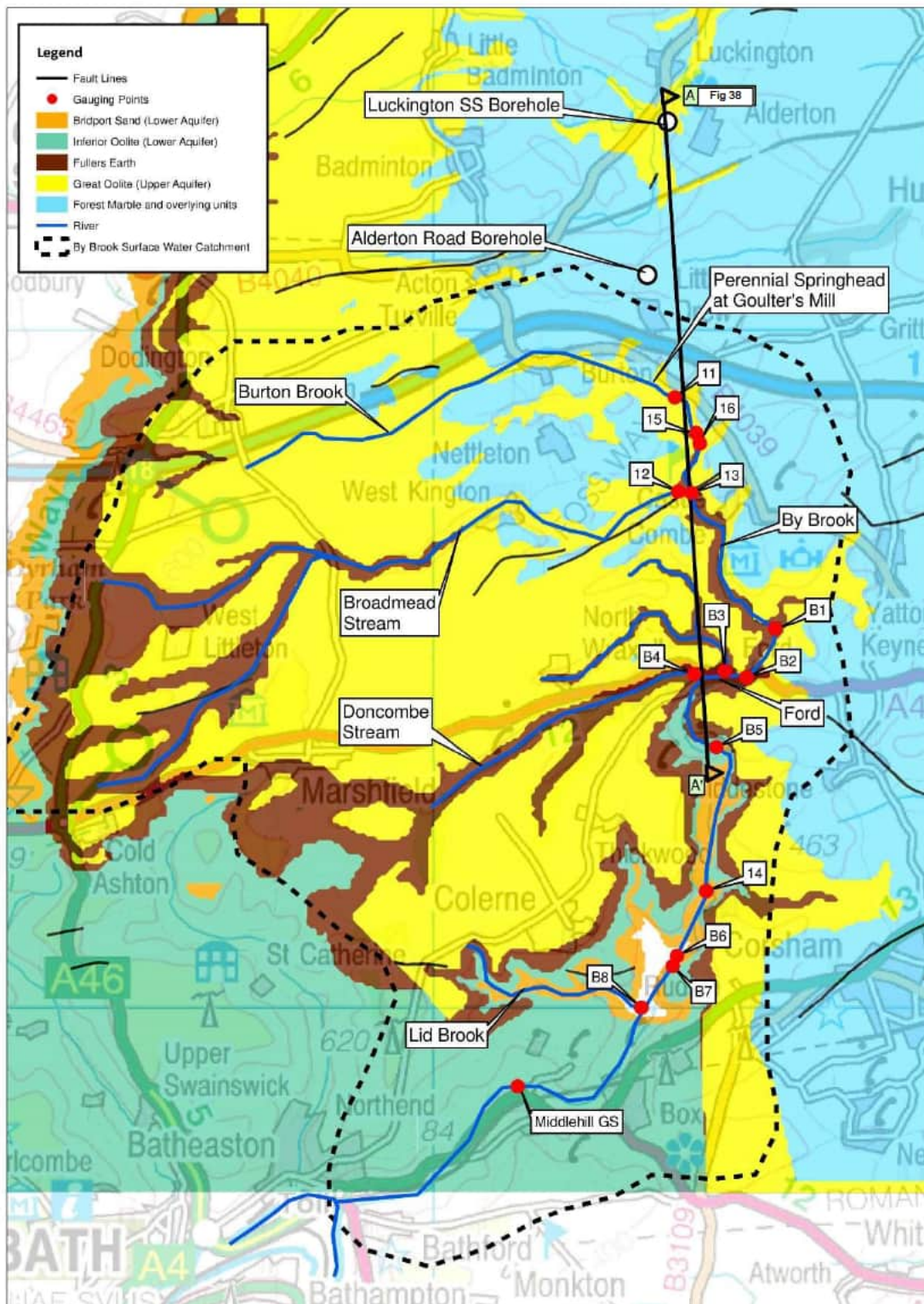
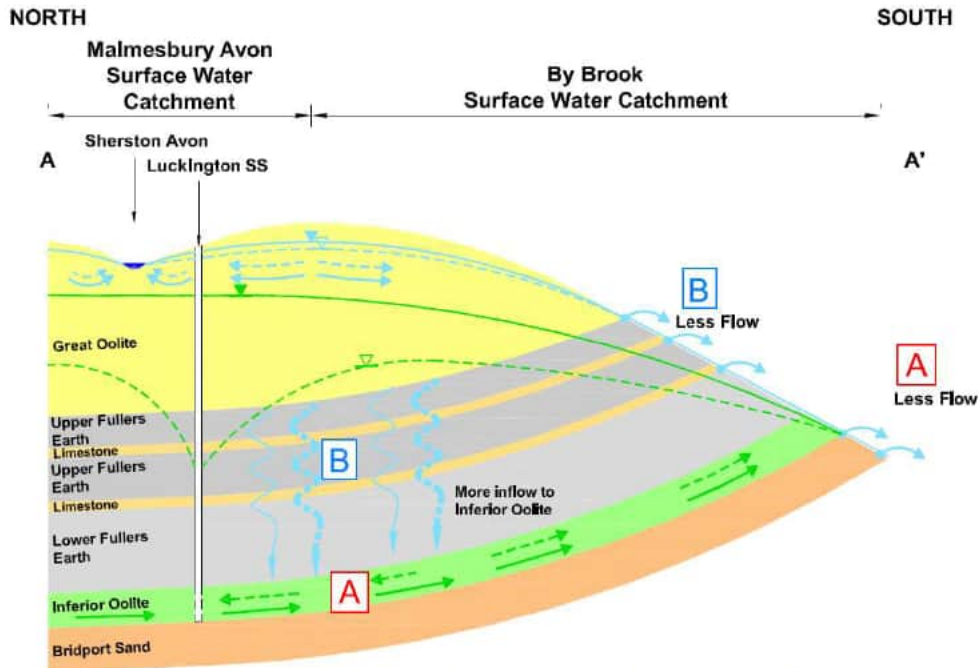


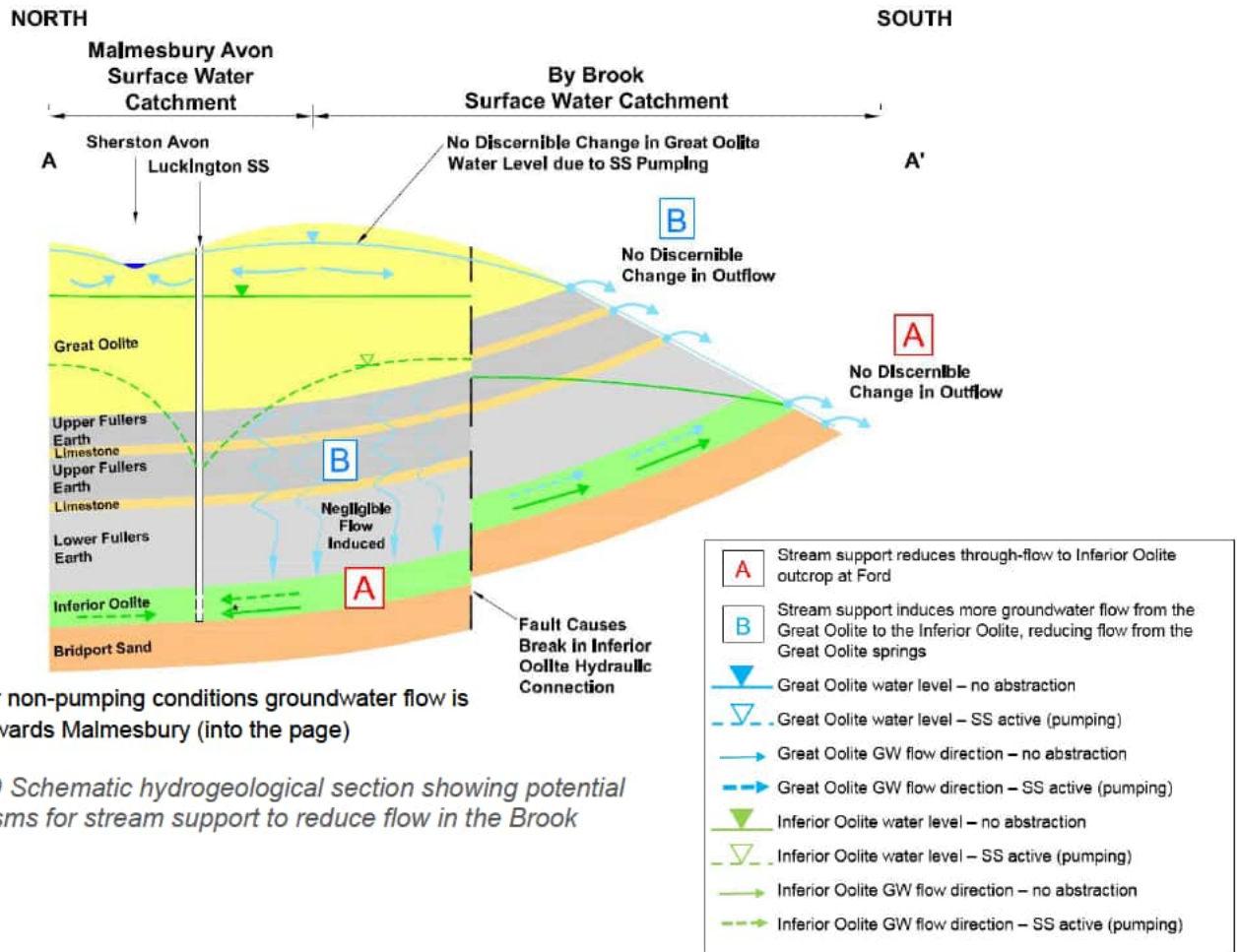
Figure 38 By Brook - simplified outcrop geology

(i) POTENTIAL MECHANISM



Note this is schematic drawing; not all the Upper Fuller's Earth limestone and clay beds are shown

(ii) CONCEPTUAL UNDERSTANDING



\* Under non-pumping conditions groundwater flow is east towards Malmesbury (into the page)

Figure 39 Schematic hydrogeological section showing potential mechanisms for stream support to reduce flow in the Brook

## Pumping trials

For this impact to be realised then water levels within the Inferior Oolite in the Malmesbury Avon and By Brook catchments will be impacted by stream support abstraction. The 2003 and 2004 SS pumping trials caused a substantial reduction in Inferior Oolite water levels e.g. >10m. The degree of impact on water levels in Inferior Oolite boreholes in the Malmesbury Avon and By Brook catchments during these trials is shown on Figure 40. These trials revealed a clear demarcation between boreholes impacted and those not impacted at the top of the By Brook catchment.

Comparison of groundwater level hydrographs shows the marked difference in hydrograph response to SS pumping. The hydrographs for four boreholes, two impacted (Badminton and Didmarton) and two show no clear impact (Summer Lane and Tormarton) are shown on Figure 41. Figure 41 also shows daily abstraction totals for stream support from the Inferior Oolite. Impacted boreholes show an increase in the rate of water level decline when abstraction starts and increases, for example the Badminton water level at the end of July declined markedly when abstraction started at Luckington. No such water level declines are observed in the Tormarton or Summer Lane hydrographs, indicating no rapid impact on these observation boreholes.

The presence of a clear demarcation of impact indicates the existence of a 'barrier' stopping the impact SS pumping propagating south beneath the majority of the upper By Brook.

## Groundwater contours

The presence of a 'barrier' to flow is also indicated by groundwater contours, even during the winter when recharge has dissipated the impact of the stream support pumping from the previous summer. Groundwater contours from February 2004 (winter high) are shown on Figure 42. Beneath the Malmesbury Avon catchment groundwater contours are widely spaced, showing flow towards to the Malmesbury Avon.

Between the By Brook and Malmesbury Avon the contours are closely spaced, indicating very steep flow gradients. It is considered that such steep gradients cannot naturally occur, as the inherent permeability of the Inferior Oolite should result in more shallow gradients as observed beneath the Malmesbury Avon. The apparent steep gradients provide evidence for the presence of flow restrictions, such as geological faults.

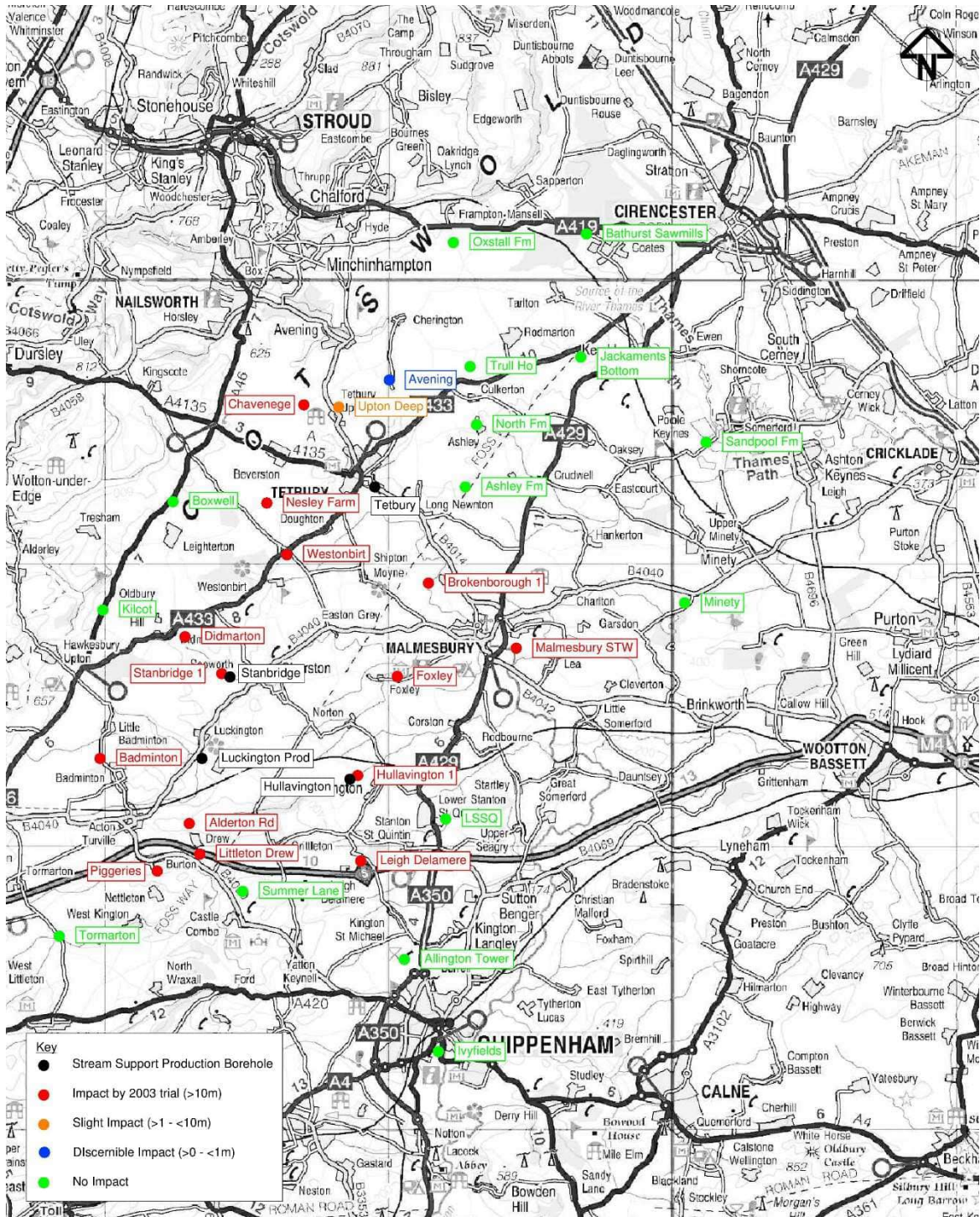


Figure 40 Lower Aquifer monitoring wells impacted by 2003 and 2004 trials

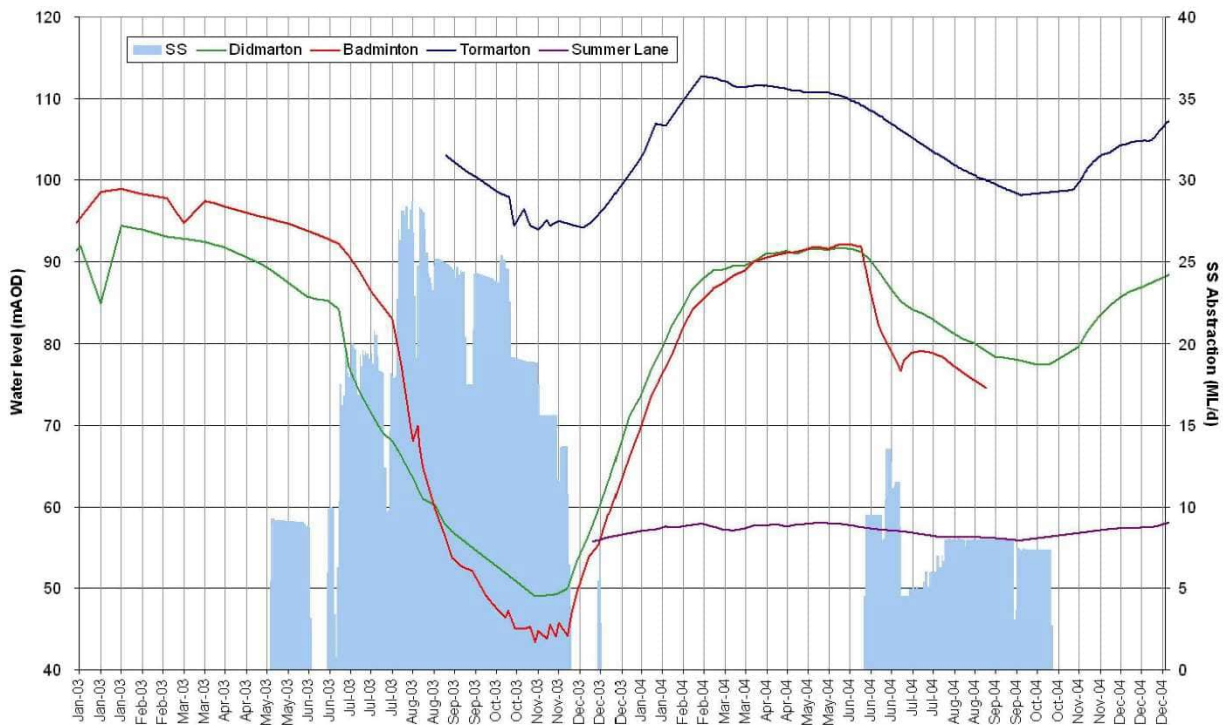


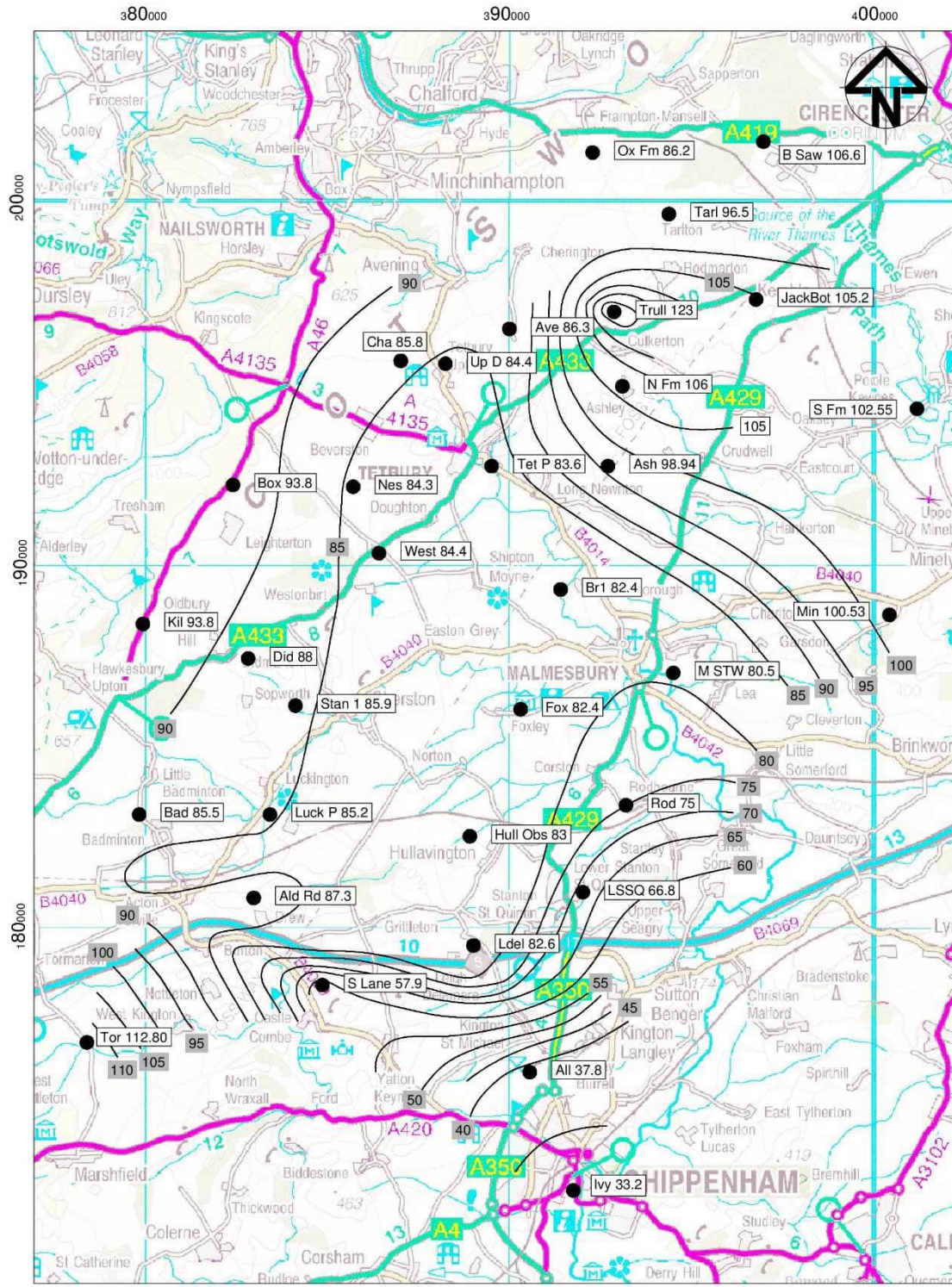
Figure 41 Inferior Oolite groundwater response to 2003 and 2004 trial

### BGS mapping

The British Geological Survey was commissioned to construct a 3D geological model for the main geological units beneath the Malmesbury Avon and By Brook catchments: Great Oolite, Fuller’s Earth, Inferior Oolite and Bridport Sand. Across the study area geological faulting is present (Figure 38) and the throw on some faults is sufficient to juxtapose different geological units.

The geology map (1:50,000 scale) shows some faulting in the Upper By Brook catchment and southern part of the Malmesbury Avon catchment. This area has been affected by localised landslip and foundering which restricts surface mapping of faults. The BGS concluded that geological mapping under represents the degree of faulting in this area. Although not mapped, faulting in this area which splits the aquifer into compartments would provide an explanation for the groundwater behaviour described above.

Evidence for the presence of faulting with sufficient throws to break the hydraulic connectivity of the Inferior Oolite is suggested from borehole logs. A line of geological section has been constructed between Luckington and the By Brook, based on driller’s logs and gamma logging. The logs used are contained in Appendix K. The line of section and associated section are shown on Figure 43. Between Alderton Road and Littleton Drew observation boreholes the data suggests a fault, with a throw of ~8-12m. The Inferior Oolite is ~12 to 17m thick in this area. Inferior Oolite groundwater level monitoring at Littleton Drew shows a SS pumping signal, but it is more muted than at Alderton Road; so the fault has not broken the hydraulic connection through the inferior Oolite, but it appears to be restricting the pumping influence southwards. As noted above the BGS reports that more faulting than mapped is likely to be present and hence the possibility exists for a complete hydraulic break within the Inferior Oolite aquifer.



Maximum Groundwater Levels: February 2004

Figure 42 Lower Aquifer 5m spacing contours plot maximum water levels

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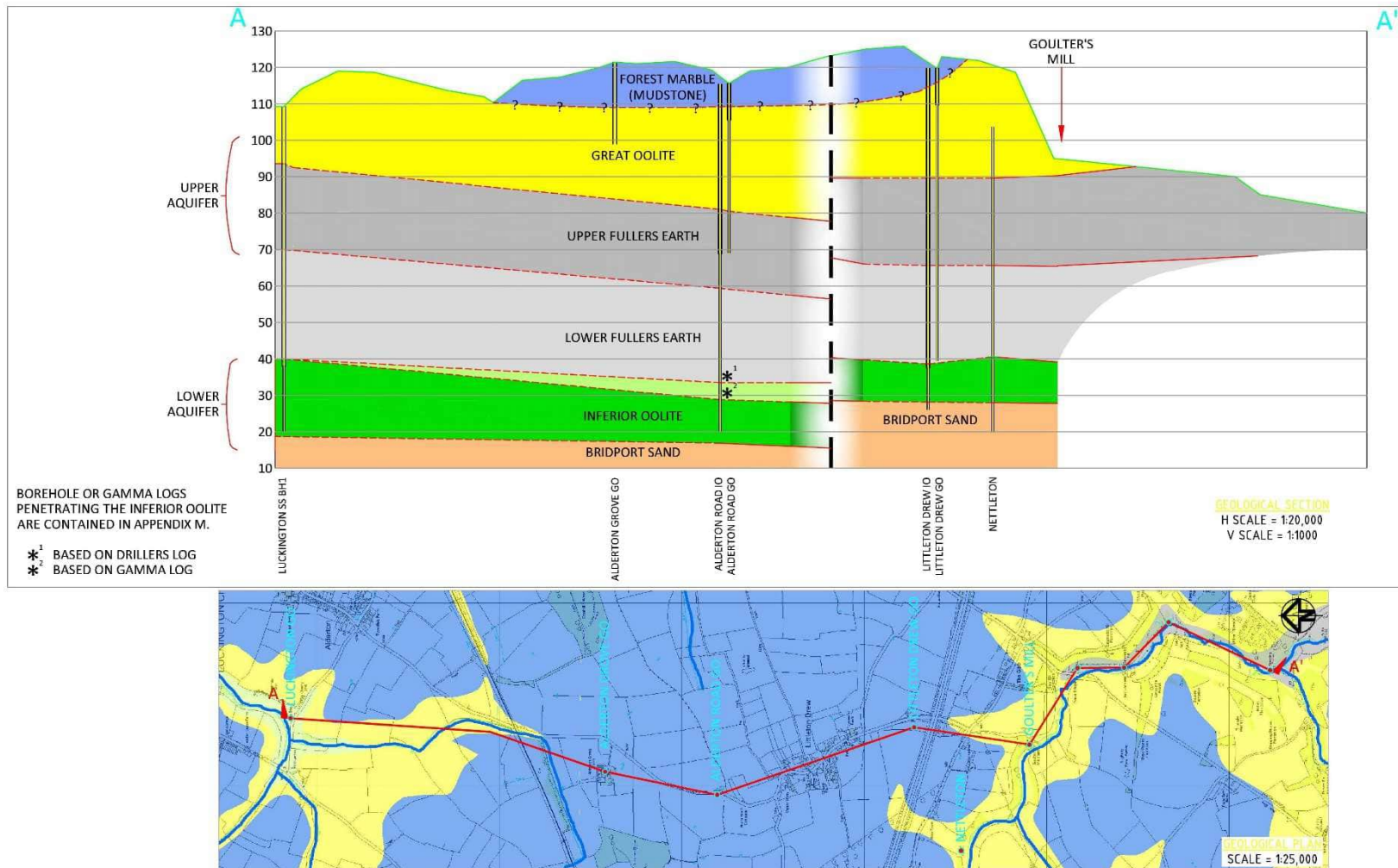


Figure 43 Geological Section - Luckington to By Brook

## Inferior Oolite outflow

Stream flow monitoring to quantify the gain of flow as the By Brook crosses the Inferior Oolite outcrop has been undertaken. If the Inferior Oolite at Ford is connected to the Malmesbury Avon Inferior Oolite then the outflow at Ford is estimated to be ~12.5 MI/d in summer, with higher outflows expected in winter (see Box 1). The results of spot gauging are shown on Figure 44, with monitoring locations shown on Figure 38.

**Box 1 :**

**Theoretical Groundwater Outflow for the Inferior Oolite Outcrop to the By Brook at Ford**

Darcy's Law:  $Q = T i W$

Where

Q = Flow rate

T = Transmissivity: 500 m<sup>2</sup>/d (results from pumping test undertaken in the Malmesbury Avon catchment).

i = gradient: 0.0025 (summer head difference between Luckington Prod borehole and Ford (20m) and distance between Luckington and Ford (8000m)). April 04: i=0.005.

W = Aquifer width: 10 km (assumed to be from scarp area (west) to Grittleton (east)).

Q = 12.5 MI/d (summer) and 25 MI/d (April 04)

The most pertinent data on Figure 44 is the accretion profiles before SS commenced in 2004 (10 June). Data for April and May show a gain in river flow across the Inferior Oolite outcrop of only 4 to 11 MI/d, whereas the predicted gain (Box 1) should be nearer 25 MI/d during these months. These relatively small measured Inferior Oolite outflows provide additional evidence that the Inferior Oolite area discharging to the By Brook at Ford is not connected to the Malmesbury Avon Inferior Oolite used for stream support.

## Conclusion

Based on the weight of evidence from pumping trials, geology, groundwater levels and stream flow data, it is considered that geological faulting has split the Inferior Oolite into hydraulically discrete compartments, forming a Malmesbury Avon compartment and a By Brook compartment. This conceptual representation is shown on Figure 39 (ii). Consequently, pumping for SS from the Inferior Oolite beneath the Malmesbury Avon catchment does not impact groundwater levels in the By Brook compartment and hence outflow from that compartment at Ford is not reduced.

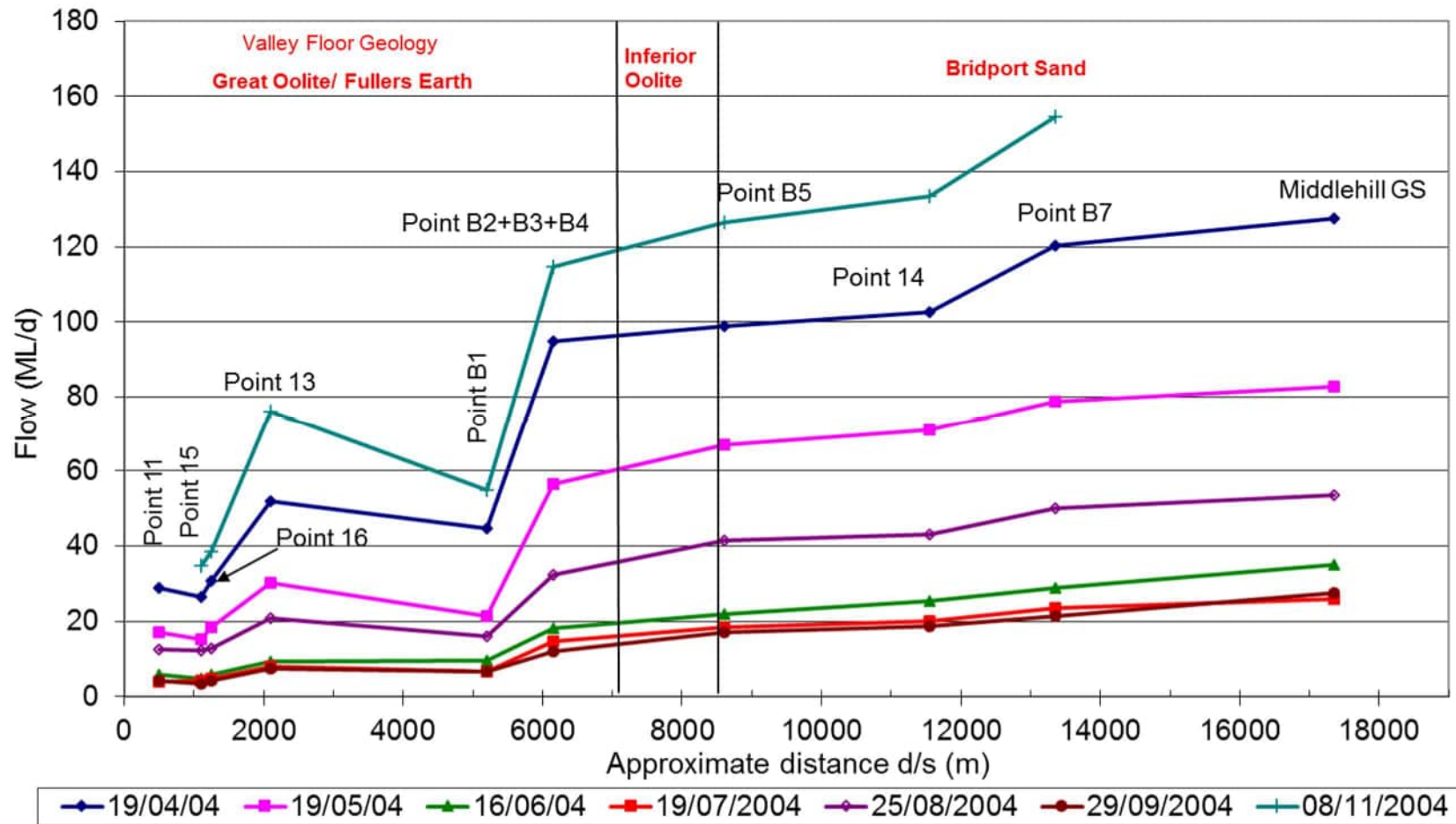


Figure 44 Flow accretion along the By Brook

### Assessing impact: Inducing leakage from the Great Oolite (Mechanism B)

Groundwater levels in the Great Oolite are at a higher elevation than the water levels in the Inferior Oolite in the area between the Sherston Avon and the By Brook. This water level difference provides the potential for water to flow from the Great Oolite to the Inferior Oolite aquifers. The magnitude of this flow has been examined by assessing the permeability of the Lower Fuller’s Earth and changes to Great Oolite groundwater levels and river flow under different SS abstraction rates.

#### Permeability of the Lower Fuller’s Earth and leakage rate

Laboratory determination of the Lower Fuller’s Earth permeability gave a value of  $1.3 \times 10^{-12}$  m/s (Appendix G), which is very low, indicating that even with a large water level difference the flow between the aquifers will be small. The potential rates of leakage are investigated in Box 2.

**Box 2**

**Theoretical Rates of leakage from the Great Oolite to the Inferior Oolite**

Darcy’s Law:  $Q = K i A$

Where

Q = Flow rate (Ml/d)

K = Hydraulic conductivity of the Lower Fuller’s Earth (m/s)

i = Gradient across the Fuller’s Earth: water level difference (winter 5m, summer 50m), divided by thickness of Lower Fuller’s Earth (20m)

A = Area over which leakage can occur, assumed to be the By Brook catchment north of the postulated fault: 22.7 km<sup>2</sup>.

K (m/s)	$1.3 \times 10^{-12}$	$1.3 \times 10^{-11}$	$1.3 \times 10^{-10}$	$1.3 \times 10^{-9}$
Winter Q (Ml/d)	0.0006	0.006	0.064	0.64
Summer Q (Ml/d)	0.006	0.064	0.64	6.4

*Note: Daily Inferior Oolite stream support abstraction range from 2.5 to 27.5 Ml/d*

To induce significant leakage the hydraulic conductivity of the Lower Fuller’s Earth needs to be 2 to 3 orders of magnitude higher than the laboratory value, such a large deviation is unlikely to occur.

A numerical groundwater model for the Malmesbury Avon Inferior Oolite compartment has been constructed. The model has been used to assess the magnitude of flow through the Lower Fuller’s Earth. Using a relatively high K value ( $1.3 \times 10^{-9}$  m/s) for the Lower Fuller’s Earth the model could not be calibrated as too much leakage was induced. The modelling work indicates that flow between the aquifers is limited.

#### Impact on Great Oolite water levels

The groundwater level in the Great Oolite Aquifer (Upper Aquifer) recorded at Alderton Road in 2003, 2005 and 2006 are shown on Figure 45 (b). Above this chart, is a chart (a) showing the groundwater levels difference (head) between the two aquifers in these years. The head differences in these years are markedly different, due to the differing amount of SS water abstracted in those years. The head difference in 2003 was ~2.5 times greater than in 2006, and hence, the flow rate between the two aquifers was ~2.5 times greater in 2003 than in 2006. Therefore, if the flow rate (also controlled by permeability) between the aquifers is significant then the Great Oolite groundwater level in 2003 should be markedly lower than 2006. However, as shown on Figure 45 (b) the groundwater level in 2003, 2005 and 2006 recessed to the same level, indicating that abstraction from the Lower Aquifer does not induce any significant leakage from the Great Oolite aquifer.

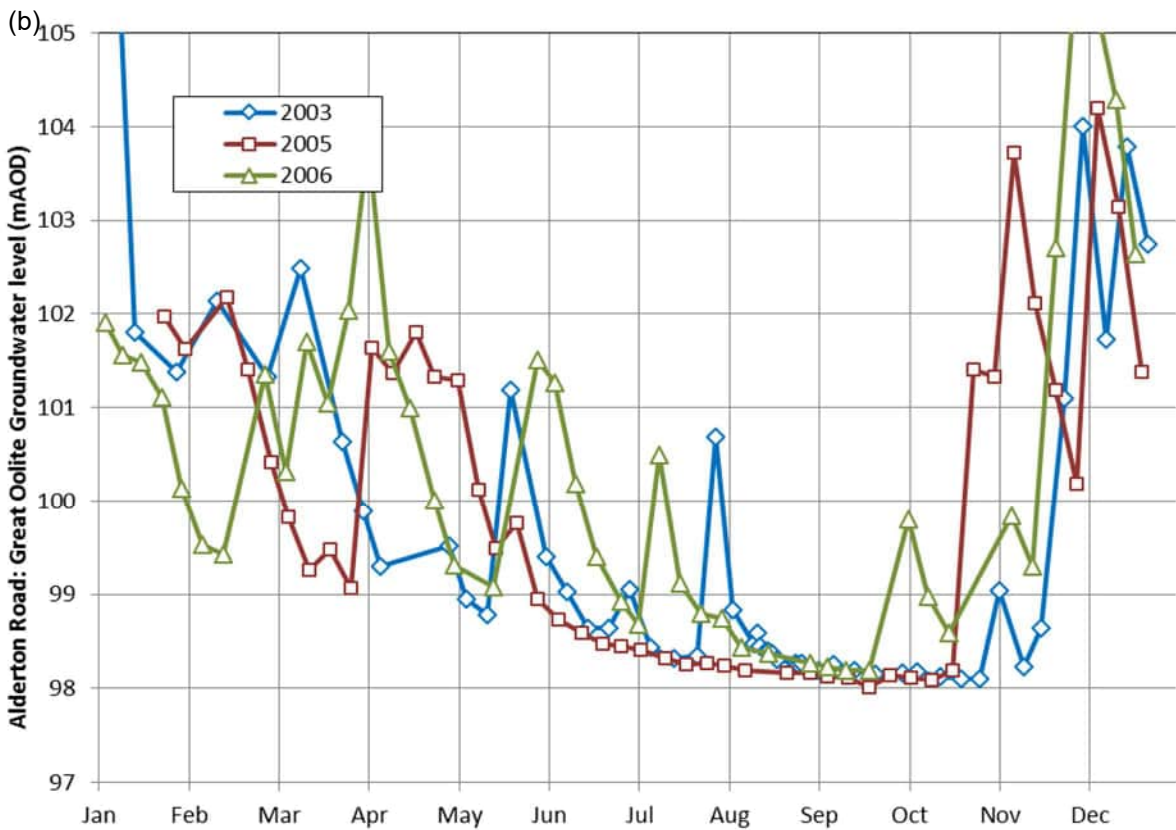
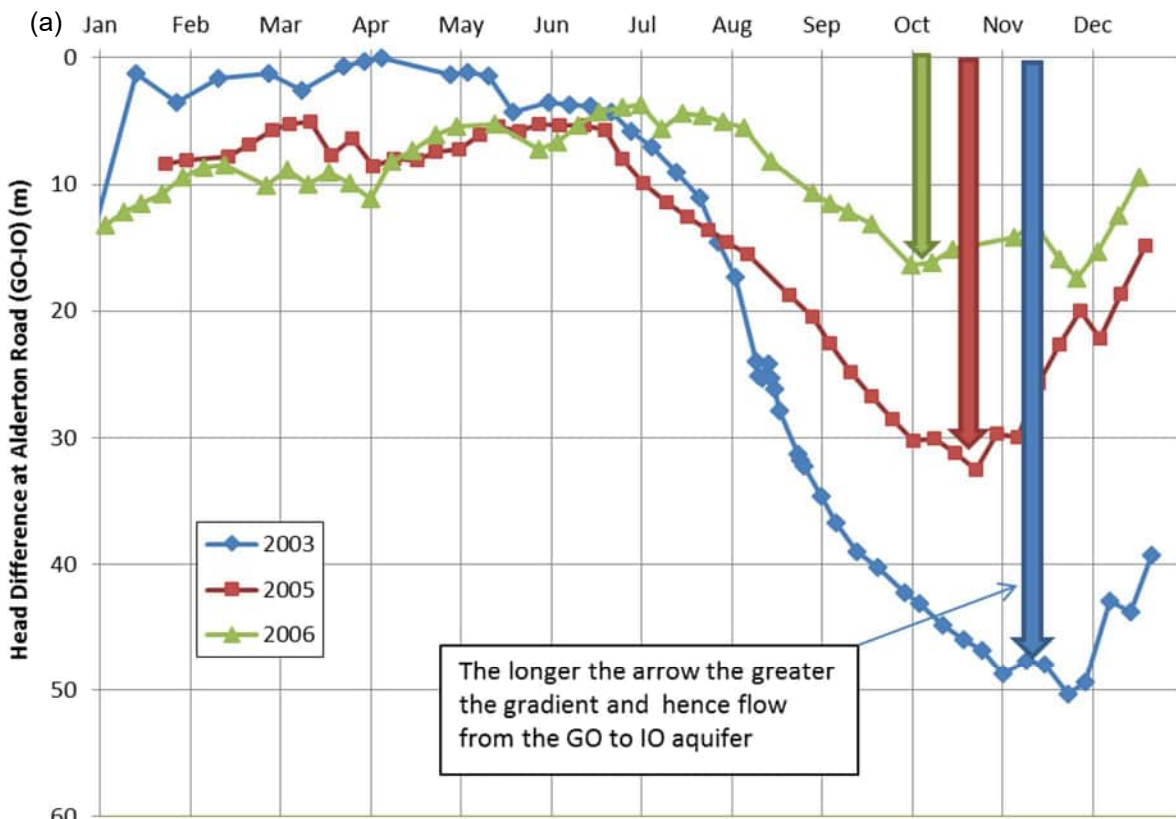


Figure 45 Alderton Rd – (a) aquifer head difference and (b) Great Oolite water levels 2003, 2005 and 2006

### By Brook flow gauging

Analysis of the spring outflow from the Great Oolite at Goulter’s Mill supports the findings from the groundwater level analysis above.

The perennial spring head of the By Brook is located at Goulter’s Mill (Figure 38). Given the proximity of the spring head to the SS abstractions, if mechanism B is significant, then the reduction in brook flow will be most acute along the head water reach downstream of Goulter’s Mill. Since June 2003 Wessex Water has routinely monitored flows in the Upper Brook.

For mechanism B to be impacting flows there should be a relationship between low Inferior Oolite groundwater levels and low flow in the By Brook. However, a correlation would be expected, as SS occurs when stream flows are low; needed to support stream flow. So, the analysis needs to identify if a causal relationship exists, such that low flows in the By Brook are made worse (impacted) by the SS abstractions. A plot exploring this relationship is shown on Figure 46. Figure 46 shows the IO water level at Alderton Rd (location shown on Figure 38) and flow in the By Brook recorded at the Fosseway (point 11, Figure 38).

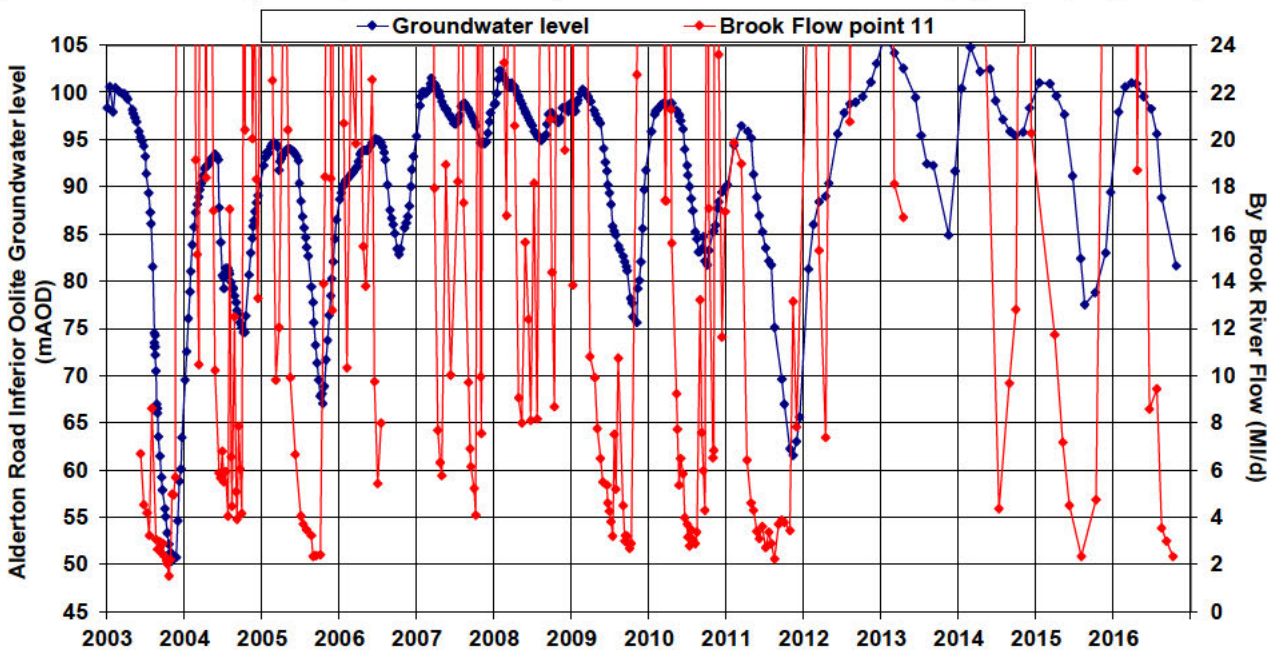


Figure 46 Exploring the relationship between flow in the by Brook and Inferior Oolite water level

Figure 46 shows that in 2003, 2005, 2009, 2011 and 2016 the Brook flows recessed to similar flows 2-3 MI/d, even though the IO water levels were at different levels in those years. The water level difference in the Inferior Oolite was 17 m lower in 2003 than 2005, consequently the potential leakage rate was 55% greater in 2003 than 2005, compared to the 2005 rate. Therefore, if leakage is significant (assuming a high K for the Lower Fuller’s Earth) then the headwater flows in 2003 should be markedly lower than in 2005, but flows are similar. It is striking that in September 2007 during the ‘dry’ September, post a very wet July (floods in Tewkesbury) that the flow recessed to 4 MI/d even though SS was not active and consequently the Inferior Oolite water level was high.

### Conclusion

Although Mechanism B exists, the low permeability of the Lower Fuller’s Earth acts to effectively hydraulically separate the Great and Inferior Oolite aquifers and any leakage is small. Consequently, pumping from the Inferior Oolite for SS does not produce a noticeable reduction in flow in the By Brook, as represented on Figure 39. The ‘low’ flows in the By Brook are therefore considered to be a natural phenomenon, with the Great Oolite needing regular rainfall events to prevent ‘low’ flows occurring.

## Overall Conclusion on By Brook impact

From the above assessments, it is concluded that flow in the By Brook is not adversely impacted by the SS abstractions in the Malmesbury Avon catchment. Geological faulting and the low permeability of the Lower Fuller's Earth preclude the SS abstractions from impacting the By Brook.

## By Brook Restoring Sustainable Abstraction Study

The By Brook has been the subject of a Restoring Sustainable Abstraction study, conducted by the Environment Agency. This study was triggered by concerns expressed by the Friends of the By Brook about the quality and quantity of water in the By Brook, namely:

- A decrease in summer flows (resulting from groundwater abstraction)
- An increase in flashiness due to motorway runoff
- Water quality problems due to sewage treatment works, farm slurry and motorway runoff.

The Environment Agency study started in 1998, with a report published in 2001 (Environment Agency, 2001). Monitoring continued in the 2000s and in 2010 the Environment Agency commissioned Professor Peter Smart, of Bristol University, to review the available data. [REDACTED] had undertaken flow gauging of the By Brook streams upstream of Ford during 1973-1975, before the Malmesbury Groundwater Scheme was active.

[REDACTED] analysis of the 1970s Brook flow data (annual low flow reading) and data collected in the 2000s did not show any brook flow dependency on Inferior Oolite abstraction rates, but flow was determined primarily by summer rainfall.

Professor Smart presented a conceptual model to explain the brook's apparent low flow behaviour, based on groundwater level behaviour and stream flow response. The head waters of the By Brook are formed by springs draining the Great Oolite. However, as described in Section 2.3, limestone bands in the Upper Fuller's Earth are included in the Great Oolite aquifer. There appears to be a dual flow component to the observed stream flows.

The Great Oolite per se is very transmissive but with low storage, consequently, the Great Oolite fills and drains quickly following rainfall. The unconfined Great Oolite in the By Brook is characterised by a total absence of long term saturated storage (Smart 2010). The other component of flow comes from the underlying limestone bands in the Fuller's Earth, which are 'semi-confined', provide a long lasting baseflow (Goulter's Mill is not known to dry). The limestones outcrop at the top of the escarpment to the west, and will be recharged during winter months and possibly also in wet summer months, giving a significant potential volume of storage despite their limited thickness (Smart 2010). Given the limited storage in these limestone bands after 2-3 months of low rainfall (with the Great Oolite 'empty' by this point) these baseflows recess to only a few MI/d, making the Upper By Brook susceptible to 'low' flows.

[REDACTED] concludes his report (Smart 2010) stating 'Overall, it is clear that low flows in the upper part of the By Brook are extremely sensitive to dry conditions. There is not however any clear evidence that stream flows are derogated by stream support abstraction from the Inferior Oolite'.

In response to this evidence and work over the past 15 years the Environment Agency concluded that there is no evidence of a link between abstraction, within or outside the catchment, and periods of low flow. Consequently, the Environment Agency has ended its investigations and formally closed the By Brook Restoring Sustainable Abstraction investigation (Environment Agency 2014).

#### 4.5.4 Protected rights

The increased daily abstraction for stream support will lower Inferior Oolite groundwater levels, such reductions could derogate private and public supply sources that also abstract from the Inferior Oolite. The potential risk of derogation is assessed in this section.

The locations of licensed and unlicensed borehole sources that abstract from the Inferior Oolite, within the compartment that is utilised for SS, are shown on Figure 47. A schematic diagram of each source borehole (plus Didmarton No1, observation borehole) showing the borehole depth, thickness of Inferior Oolite and depth to pump are shown on Figure 48. Also, marked on each borehole (Figure 48) is the minimum groundwater level recorded in each borehole during the 2003 pumping trial. During the 2003 trial none of these sources were derogated.

Using the minimum 2003 groundwater levels and depth to pump, the sources most sensitive to low water levels can be identified, these are:

- XX
- YY
- ZZ

The most vulnerable source is ZZ. To avoid derogation at this and other sources, it is assumed a minimum water column of 3 m is needed above the pump (or base of aquifer). For the ZZ borehole not to be derogated the borehole water level needs to stay above 44 mAOD. The water level at Didmarton No1 and ZZ are very similar (though a gradient does exist between them), and therefore, the former can be used as surrogate for the ZZ. As Didmarton borehole is routinely monitored (Environment Agency telemetry, every 15 minutes) it will be used to monitor the ongoing risk to these sources. Therefore, if the water level at Didmarton stays above 43 mAOD, then the ZZ borehole (and other sources) will not be derogated, hence 43 mAOD is defined as the 'derogation prevention level'.

The numerical model has been used to assess the potential impact of increased SS abstraction on these sources. The model has been run to assess the Inferior Oolite groundwater level than would have occurred during 1978 to 1996 (Figure 49) using the SS pumping pattern required to maintain target river flows. This model scenario is run m810, (see Table 11) which assumes a precautionary approach regarding the proportion of the Shipton Moyne yield obtained from the Lower Aquifer i.e. 100% in summer.

Restoring Sustainable Abstraction – Malmesbury Avon

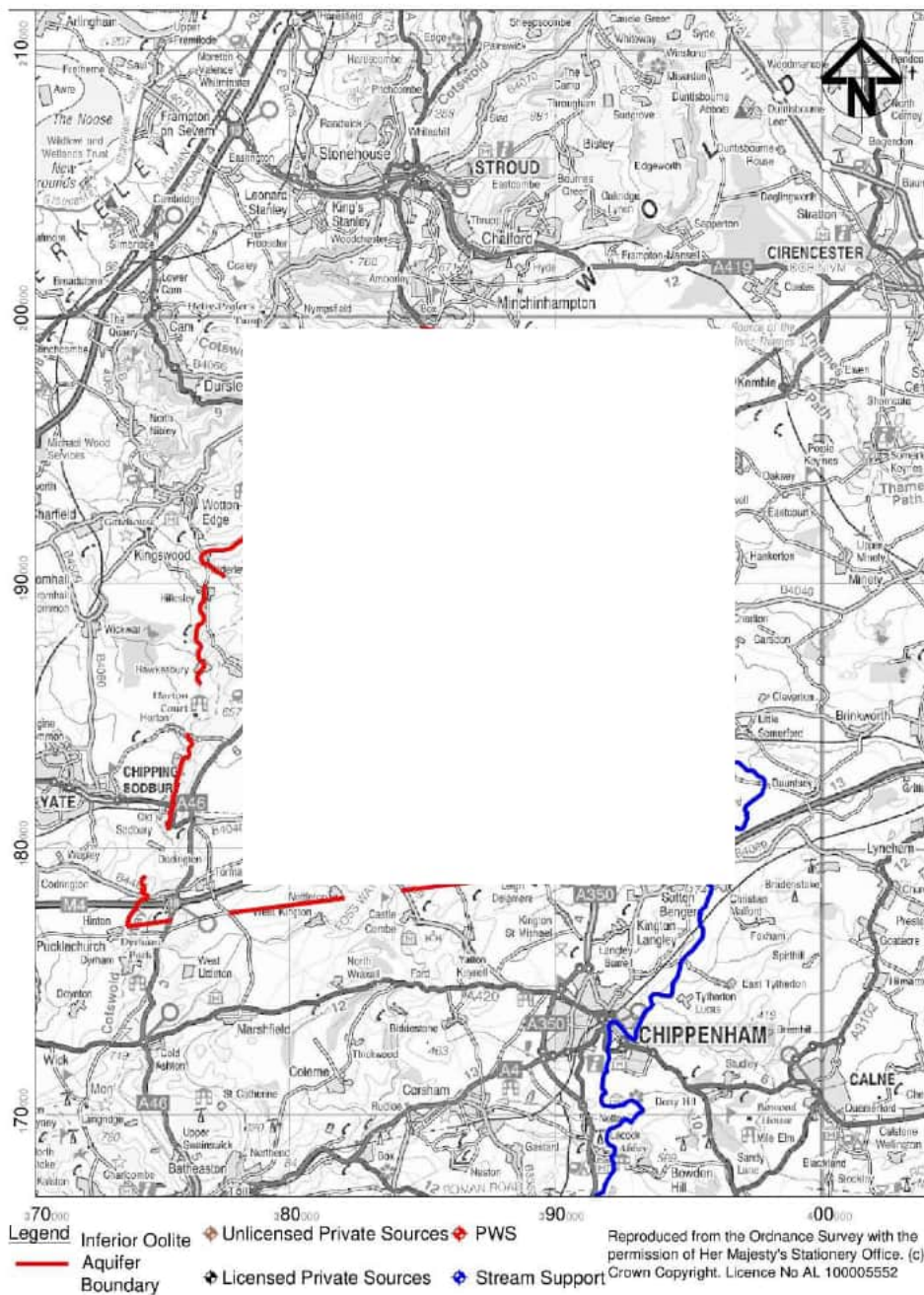


Figure 47 Location of protected rights utilising the Inferior Oolite

Restoring Sustainable Abstraction – Malmesbury Avon

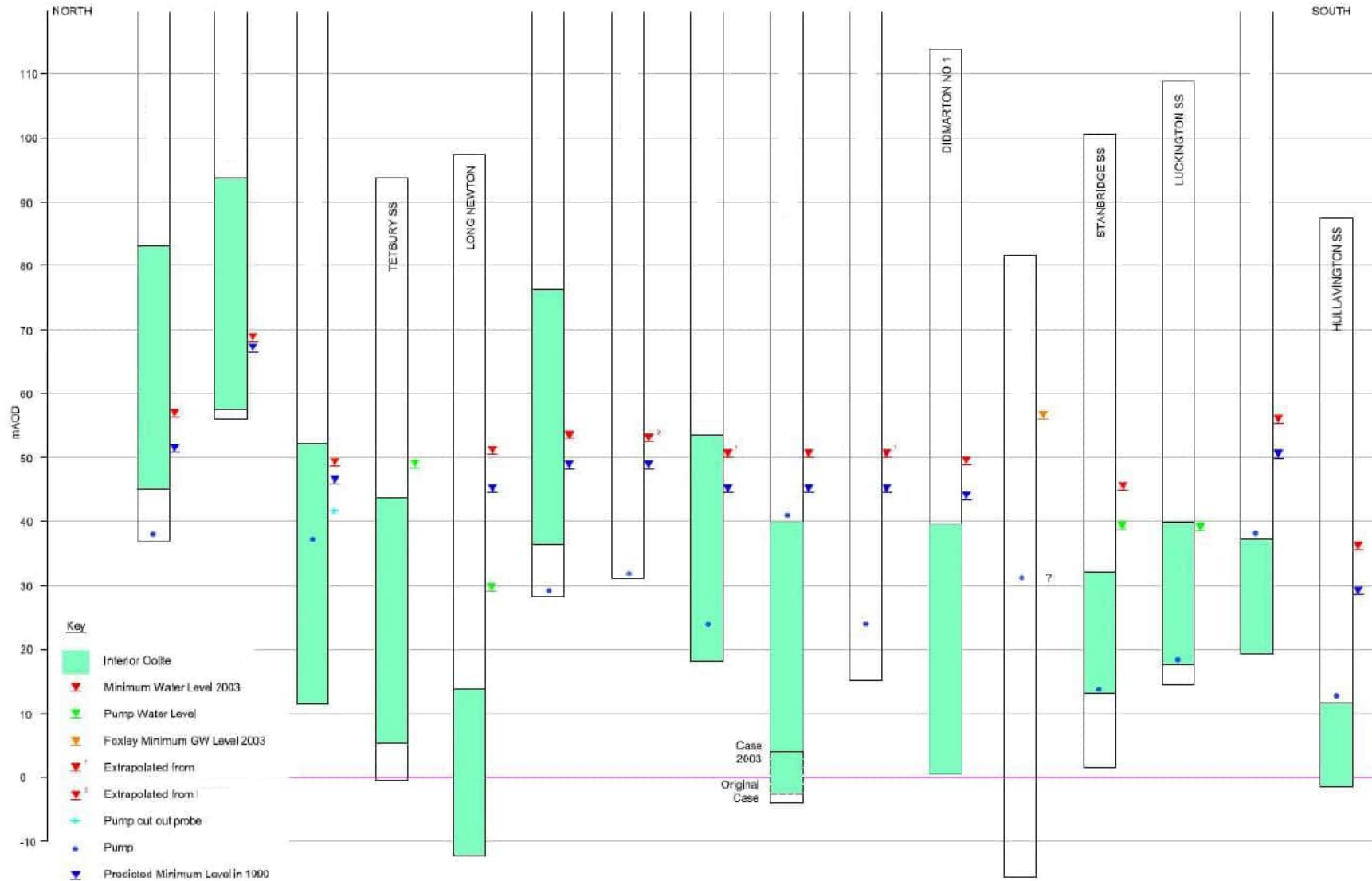


Figure 48 Protected rights: Borehole details, 2003 minimum water level and modelled water level in 1990 (m806)

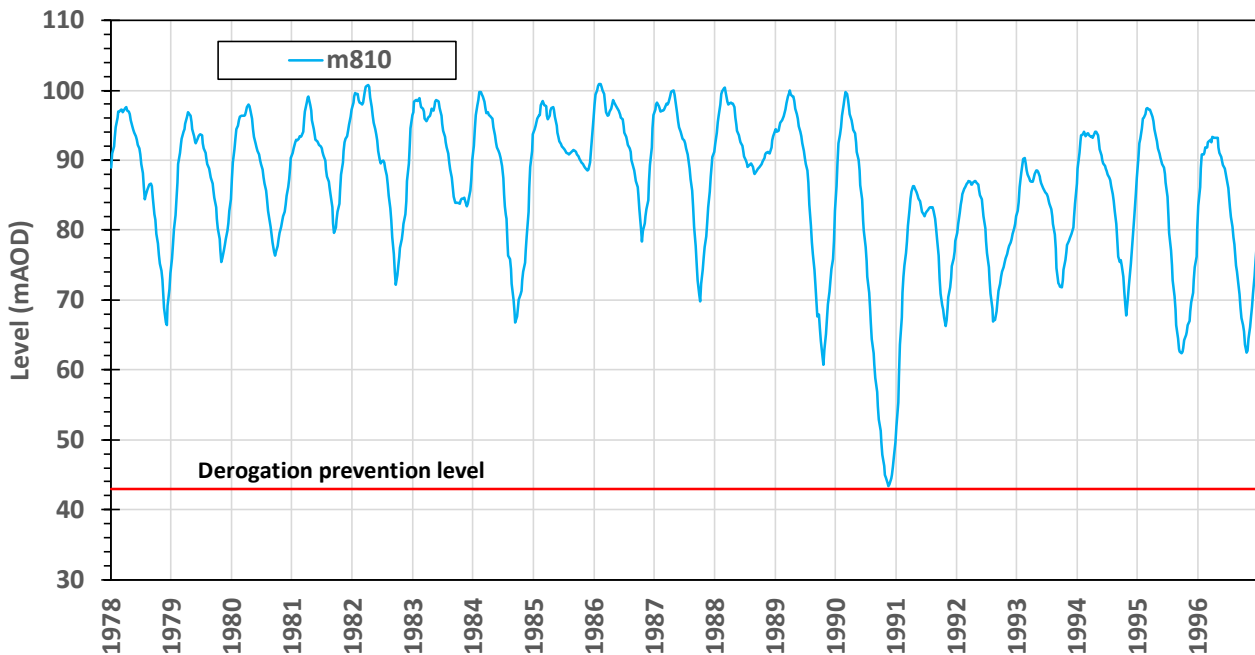


Figure 49 Didmarton water level based on proposed licence use (m810)

The Inferior Oolite water level at Didmarton in 2003 recessed to 48.9 mAOD. Figure 49 shows that the model predicts the minimum groundwater level, under 1990 conditions, to be 43.40 mAOD.

Therefore, under 1990 conditions the abstraction of 3742 MI (4142 MI inc. Hullavington) from the Inferior Oolite aquifer to support river flows will lower the Inferior Oolite water level at Didmarton by a further 5.50 m, compared to the minimum level recorded in 2003. The 2003 water level at each protected right has therefore been lowered by 5.50m (Figure 48, except XX, not a 1:1 correlation) and the residual water column above the pump or base of the aquifer (YY) calculated. As the water level across the Inferior Oolite compartment used for SS are well connected (relatively ‘flat’ water table), this is considered to be a reasonable approach.

All the protected rights have a residual water column of greater than 3 m, but ZZ only just exceed this level. The ability to increase the safety margin at the ZZ borehole is discussed below.

**ZZ:** This borehole was drilled and constructed to draw water from the full thickness of the Inferior Oolite, however, the pump is located at the base of the Lower Fuller’s Earth. Wessex Water has explored options to lower the pump, but no viable option was identified.

However, rather than seeking to address individual issues, Wessex Water, Bristol Water and Environment Agency agreed a better, more sustainable approach, was to ensure the aquifer water level remained further above the ‘potential derogation level’. To achieve this, less abstraction from the Inferior Oolite or more recharge to the Inferior Oolite has to occur. Options to ensure the Inferior Oolite water remained above the ‘potential derogation level’ have been examined, a total of 10 options were considered, and summarised in Table 13. A full account of the options appraisal exercise was detailed in Wessex Water’s 2014 Water Resources Management Plan (Wessex Water 2014).

Table 13 Options appraisal to ensure sustainable use of the Lower Aquifer

Option No	Description	Appraisal Comment
1	Aquifer Storage and Recovery (ASR) – Luckington/Stanbridge, winter refilling	No additional resilience Treatment may be required – extra cost
2	ASR – Foxley, winter filling	Has some hydrogeological uncertainty Treatment may be required
3	1.5 MI/d Bristol Water reduction. Refurbish abandoned sources to balance reduction	No additional resilience
4	1.5 MI/d Bristol Water reduction, Wessex Water pipeline transfer to Bristol Water	Limited additional resilience
5	1.5 MI/d Bristol Water reduction, Wessex Water reduce import to Bath by 1.5 MI/d	Dry weather/drought resilience for Inferior Oolite water levels and increased Bristol Water PWS resilience
6	1.5 MI/d Bristol Water reduction, Wessex Water reduce Bristol Water import by 1.5 MI/d into Bath, plus 1.5 MI/d Bristol Water reduction (control curve), Wessex Water pipeline transfer to Bristol Water	Meets objectives (combination of Options 4 & 5)
7	7.5 MI/d Bristol Water winter reduction with Wessex Water pipeline transfer to Bristol Water: Winter transfer	Dry weather/drought resilience for Inferior Oolite water levels and increased Bristol Water PWS resilience
8	New Great Oolite public water supply for winter use only	No additional resilience. Winter use potentially restricted in dry winters
9	Great Oolite used for stream support with pipeline from Rodbourne to Luckington	Dry weather/drought resilience for Inferior Oolite water levels. Only achieves a 0.94 MI/d reduction in Inferior Oolite abstraction.
10	18 MI/d Great Oolite PWS reduction seeking to reduce stream support need by 1.5 MI/d	No additional resilience. Considerable uncertainty, best estimate indicates it only achieves a 1 MI/d reduction in Inferior Oolite abstraction.

The conclusion from this appraisal was to take Option 6 forward. Option 6 refers to two 1.5 MI/d tranches: 1) relates to the 1.5 MI/d additional reduction compared to the MoU commitment, see Section 4.4.1 (proposed abstraction licences (m809)). The second 1.5 MI/d, is a further 1.5 MI/d restriction when periods of 'low groundwater level' begin defined by a groundwater (Didmarton) control curve. The working control curve is shown in Figure 50. The curve (lower) was derived with reference to the rate of recession in 2003, during the 'signal test' and seeking to maintain a winter water level of 90 m AOD, when the aquifer is viewed as 'full'. A second (upper) control curve is also shown on Figure 50, this is set to give operational flexibility when the aquifer is 'full' and during 'wet' summers, when the aquifer is not being overly stressed.

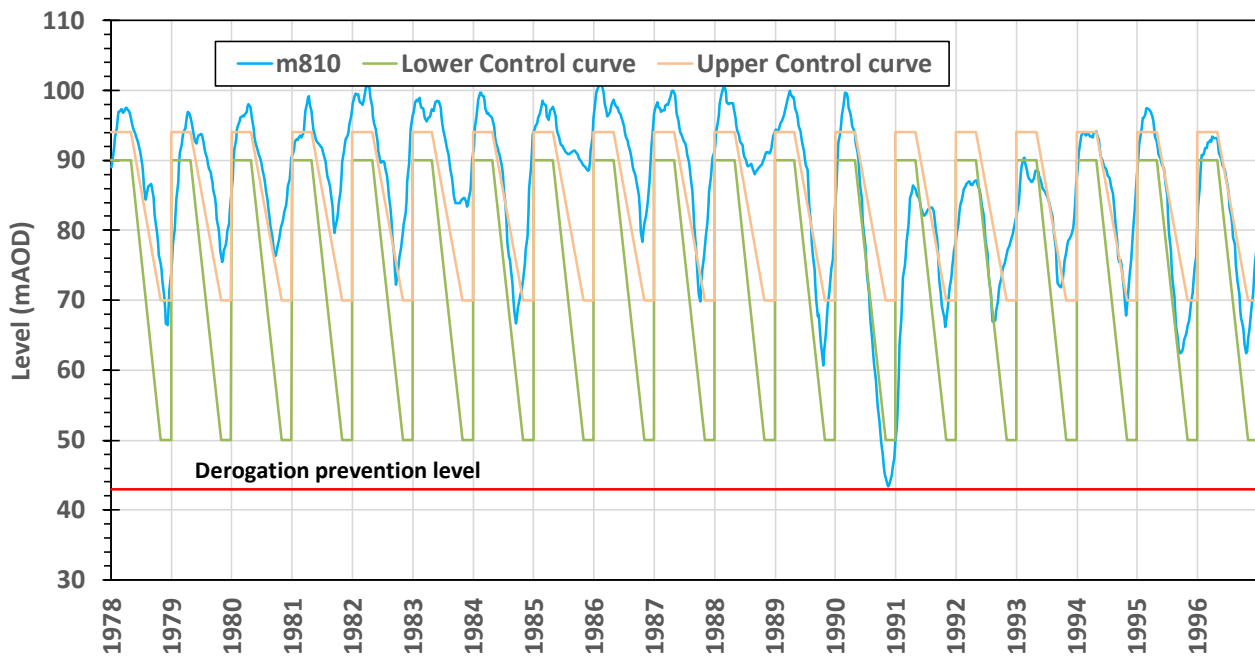


Figure 50 Didmarton control curve and Didmarton hydrograph Run m810

Unfortunately, it is not possible for the numerical model to automatically reduce the PWS output with reference to the modelled Didmarton control curve water level. Therefore, the Lower Control Curve has been manually overlain on the Didmarton hydrograph from run 810, to identify periods when a lower PWS abstraction rate would occur. In 1990-1991, 323 days (9 July 1990 to 27 May 1991) of lower PWS output is calculated, a net PWS reduction of 484.5 MI. Compared to an average (1978-1996) PWS of 4.76 MI/d, the control curve reduces this average to 4.61 MI/d (reduction of 0.15 MI/d). The resultant PWS abstraction rate time series was then run in the model, run m811. This is the same as run m810, but lower PWS abstraction at times, due to the Lower Control Curve. The Lower Control Curve has little influence from 1978 to 1988, so the resultant modelled Didmarton hydrographs for the period 1989 to 1992 are shown on Figure 51. The PWS reduction increase the margin of safety above the prevention level by ~2.5m. The influence of the Upper Curve has not been modelled, as it only influences PWS use in 'wet' conditions.

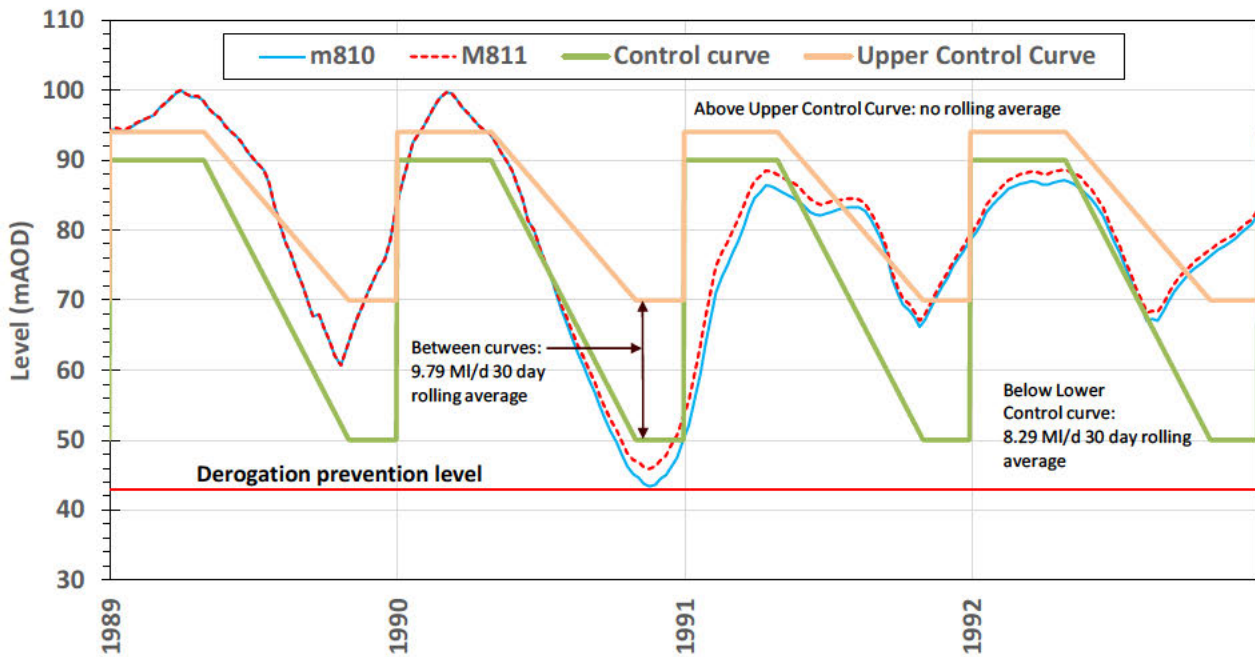


Figure 51 Modelled Didmarton water level under proposed full licence use (m810) and with a control curve restricting PWS use (m811)

The following abstraction rules are understood to apply in relation to the control curves (Section 6.3.3):

- Above the Upper control: no rolling average, up to 12.1 MI/d can be taken;
- Between the Control Curves: 9.79 MI/d 30 day rolling average, up to 12.1 MI/d can be taken;
- Below the Lower Control Curve: 8.29 M/d 30 day rolling average, up to 12.1 M/d can be taken.

The PWS reduction to achieve this positive outcome means that Bristol Water loses 1.5 MI/d in deployable output. To address this shortfall, Wessex Water will supply Bristol Water with 1.5 MI/d from the Cowbridge source (Great Oolite) when Bristol Water reduces its abstraction based on the Lower Control Curve. A pipeline between Cowbridge and Shipton Moyne to allow this transfer is being constructed in 2017. Water abstracted from Cowbridge for the transfer will be within the proposed licensed quantities.

In addition, the pipeline connection will have the added benefit of increasing supply resilience, with the pipe line sized to transfer up to 3 MI/d.

## 4.6 Residual impacts

The residual impacts of increasing Inferior Oolite abstraction for stream support are:

- Reducing outflow from the Inferior Oolite to the Great Oolite aquifer and hence Malmesbury Avon in the autumn and winter - however, this loss of flow is not considered to be significant as river flows will be substantial at these times upon the onset of winter recharge.
- Reduced flow in scarp slope springs – whilst the flow to the scarp slope springs will be less compared to their natural flow, the reduction will be less than it was historically (pre 1999) and considerably less than if the current licences were to be fully utilised.

## 5 Environmental status

### 5.1 Introduction

The trialling of increased SS during and since 1995 has maintained the target flows along the Malmesbury Avon and its tributaries (Tetbury and Sherston). The environmental monitoring data collected during this period can therefore be assessed to identify if the target flows provide an acceptable amenity flow and 'healthy' river ecology. The environmental data is assessed in this section.

The Malmesbury Avon is not subject to any environmental designations e.g. SSSI or SAC. Part of the Malmesbury Avon catchment lies within the Cotswold Area of Outstanding Natural Beauty.

### 5.2 Water quality

Water from the Inferior Oolite aquifer abstracted at Luckington, Stanbridge and Tetbury, as result of these proposed licence changes, will at times provide the vast majority of the flow in the Malmesbury Avon, rather than the Great Oolite. However, geochemically the Inferior Oolite water from these sources is effectively identical to the Great Oolite, so the chemical quality (excluding anthropogenic inputs) of the two waters is the same, hence the river ecology will not experience an adverse quality change due to stream support changes. The stream support water is naturally low in dissolved oxygen, the localised effect this has on the river ecology is discussed in Section 5.5.2.

The Malmesbury Avon does exhibit raised nitrate and phosphate levels; these being derived from sewage effluents and agricultural runoff. In addition, the Great Oolite aquifer, providing baseflow to the river can have raised nitrate levels. However, the nutrient loading is not a consequence of stream support, as the Inferior Oolite stream support water has 'very low' nutrient levels i.e. nitrate typically <0.2 mg as N/l. In fact, the Inferior Oolite stream support water can be viewed as providing dilution when active.

### 5.3 Amenity

The visual appearance of the river in the late-1980s to mid-1990s led to numerous complaints being received by the Environment Agency and its predecessors. The flow in the Sherston Avon at Malmesbury in July 1995 was only a trickle (Figure 3). The river at Malmesbury is an integral part of the town and its historical setting. The maintenance of an acceptable amenity flow is therefore essential. To aid in defining an 'acceptable amenity flow' for the Sherston Avon and Tetbury Avon, the Environment Agency asked several local residents, who frequently visited the river, to keep a diary detailing their opinions on the appearance of the river. The records from these river diarists were used by the Environment Agency to set the target flow values in Malmesbury at St John's Bridge and Abbey Weir.

Since August 1995, the use of increased stream support has allowed the river flow targets to be maintained. It is noted that since August 1995 the Environment Agency have received no complaints from the general public regarding the poor appearance of the river due to low flows, except for one letter in 2009. This referred to the appearance of the river downstream of the Tetbury-Sherston confluence, in the Baskerville part of Malmesbury. During 2009 all the target flows were maintained. Wessex Water requested more details about the complaint, location and date, but no further information was forthcoming.

The findings from this study were presented at a public meeting, hosted by the Malmesbury River Valleys Trust in June 2006 and 2010. The meeting attracted ~30 members of the public. The consensus from the meeting was that there was no longer a low flow problem.

## 5.5 Ecology

### 5.5.1 Description of area

The ecology of the Malmesbury Avon and its tributaries is heavily influenced by the calcium rich spring fed headwaters and historic river management practices. The Sherston and Tetbury arms have similar plant communities containing mosses and submerged higher plant species such as water starwort and crowfoot in unshaded sections with marginal herbs such as true and fool's-water-cress becoming dominant in autumn as river flow naturally recedes. Further downstream the emergent plants, branched bur-reed and reed sweet-grass, become more abundant. A dense covering of blanket weed occurs at some unshaded sites especially in shallow reaches.

A diverse invertebrate community is supported in the Sherston and Tetbury arms with a range of mayfly, stonefly and caddis fly and the increasingly threatened white-clawed crayfish. White-clawed crayfish are listed in the UK Biodiversity Action Plan (UK BAP) as this species is restricted to a diminishing number of areas due to the spread of crayfish plague and the introduction of non-native crayfish species. The Sherston and Tetbury arms also support a community of brown trout, bullhead and stone loach and a variety of coarse fish in the lower reaches.

Around Malmesbury, and in the main river below the town, the river widens and deepens with a noticeable change in the plant community. Species associated with larger slower rivers occur including; yellow water lily, unbranched bur-reed, greater rush, arrowhead and water milfoil. These are typical of a wider clay catchment river that the Malmesbury Avon becomes. Coarse fish such as chub and roach dominate and the invertebrate community changes with molluscs becoming more abundant than in the upper reaches.

Other aquatic UK BAP species such as otters and water voles are present on the Malmesbury Avon. Otters are recolonising the Bristol Avon River having disappeared in the 1970s and evidence has recently been found below Malmesbury and on the Sherston Avon. Kingfishers are also often seen in the area.

### 5.5.1 Ecology investigations and assessment methods

Since 1995 the Malmesbury Avon has been receiving increased stream support to meet the new flow targets. During this period, the ecology of the river would be expected to have adapted to these flow conditions allowing a valid assessment of the ecological quality to be made. In this section, the existing ecology is described and its quality judged. Where there is considered to be evidence that the ecology falls short of that expected then the reasons have been examined and the influence of river flow discussed.

Ecological surveys have concentrated on examining the aquatic plant, macroinvertebrate and fish populations in the Malmesbury Avon and its tributaries. These groups are all influenced by flow regimes and can be used to a greater or lesser extent to objectively assess the suitability of the existing (proposed licence) arrangements. A detailed description of the assessments techniques is given in Appendix L1.

#### Macroinvertebrates

Specific monitoring has been undertaken since 2001 to establish whether revised flow targets and the stream support arrangements have resulted in a healthy ecology that would be expected from such a river given adequate flow. Surveys were undertaken in 2001, 2002, 2004, 2006 and 2008 at ten sites along the river network and have been continued at three sites each year since 2012. The data collected have been used to assess the macroinvertebrate community in regard to the existing flow regime.

The aquatic macroinvertebrate community at any site is adapted to the flow conditions experienced. For example, the invertebrates present in fast flows may rely on the current to bring food into nets spun for the purpose or may simply experience less predation by their ability to survive in extreme conditions. As flow rates drop so does the velocity and therefore the competitive advantage may be reduced. The macroinvertebrate data collected have been assessed using the Lotic-invertebrate Index for Flow Evaluation (LIFE) (Extence et al 1998). This method of scoring takes the changes described above into account and gives a score that reflects the communities response to flow conditions.

A detailed description of the methodology used to generate the sample (observed) LIFE score is given in Appendix L1. The observed LIFE score is compared to the LIFE score calculated from the macroinvertebrate community predicted for the site. The community prediction is generated by the RIVPACS software (See Appendix L1). This software is the basis of the RICT tool that was developed for assessing the quality of the macroinvertebrate community for Water Framework Directive (WFD) purposes. The LIFE score is the most appropriate index for assessing flow suitability in the Malmesbury Avon and an Environmental Quality Index (EQI) has been derived by dividing the observed by the predicted score. An EQI of <1.0 indicates a measure of flow related stress i.e. the taxa present reflect a lower flow velocity than that predicted for the site.

The Environment Agency also uses RIVPACS for assessing river water quality whereby macroinvertebrate taxa are given a Biological Monitoring Working Party (BMWP) score depending on the sensitivity to organic pollution. The Average Score Per Taxon (ASPT) is compared to that of the predicted community to provide an EQI that can be used to quantify the macroinvertebrate community response to organic pollution. There is a degree of correlation between the LIFE and BMWP scoring systems as invertebrates requiring high current velocity often require high dissolved oxygen and are therefore sensitive to organic pollution. A low LIFE EQI can at times be attributed to organic pollution and the ASPT needs to be considered to help differentiate between the two potential impacts.

The Environment Agency also routinely undertakes macroinvertebrate sampling in the river as part of its routine monitoring. Where appropriate these data have also been used in this assessment.

## Fish

The results of electric fishing surveys of the Malmesbury Avon undertaken by the Environment Agency, Wessex Water and the Game Conservancy Trust have been used to assess fish populations.

## Macrophytes

Macrophyte (aquatic plant) surveys were undertaken at the macroinvertebrate sites in 2002, 2004, 2006 and 2008. There are also historic data from eight sites on the Malmesbury Avon recorded in 1992-95 and described in Holmes (Holmes 1996). These sites were re-surveyed by Wessex Water in 2001.

Macrophytes are adapted to different flow conditions allowing conclusions to be drawn about the flow experienced by a recorded community. Most water crowfoot species, for example, have long narrow leaves that offer low hydraulic resistance to flow and thrive in faster flows. A much greater hydraulic resistance is experienced by bushier plants such as water-cress and Canadian pondweed that are more often found in slower flow conditions.

As with macroinvertebrates, an assessment of flow impact is made by comparing observed with predicted macrophytes taxa at a survey site. Survey methods and assessment procedures are described in Appendix L1. The site survey is given a Macrophyte Flow Rank (MFR) score. This method that has been superseded by Leafpacs that is used for WFD assessments however the MFR does give a flow specific score that is appropriate in this context. The higher the score, the higher the flow velocity with which the macrophytes are associated. The difference between observed and expected (benchmark) MFR (Table M11.2 in Appendix L1) is taken as an indication of potential flow related stress and provides the Current Ecological Rating (CER). A CER of 0 indicates no flow related stress, whilst 4 indicates a community severely changed from that expected.

## Blanket weed

Excessive blanket weed has been identified as an amenity issue during low flow periods.

Blanket weed is a term that is sometimes used generically to describe any fouling algae but usually refers to *Cladophora* and *Vaucheria* which thrive in well lit, often shallow, slower flowing, nutrient rich conditions. *Cladophora* will also thrive in faster flowing conditions as long as there is a stable substrate for it to attach to. Another macrophytic algae that is sometimes referred to as blanket weed is *Enteromorpha*. This can bloom in sections of very slow flow and high nutrients levels. One site where this has been seen is on the Tetbury Avon at Abbey Weir where mats of it float to the surface due to gas bubbles forming in the tubular colonies. Colonies of diatoms often cover the substrate and submerged plants producing brown, mucilaginous strands.

This can also be referred to as blanket weed and look unsightly. It is more likely to occur where there is low current velocity.

A survey measuring percentage cover of blanket weed and distinguishing between the different types of algae was carried out annually between 2002 and 2008 in early summer before the onset of stream support and in September-October while stream support was still operating (except in 2008 when SS from the Inferior Oolite sources did not occur). Initially 11 sites were recorded and this was later increased to 13 in 2004.

## 5.5.2 Results of ecological assessment – macroinvertebrates

The results of macroinvertebrate surveys undertaken between 1995 and 2016 have been used in this assessment. The LIFE scores and other taxa scores are summarised in Appendix L2. A list of taxa and their abundance recorded on each sampling occasion is contained in Appendix L3.

The observed LIFE scores have been averaged for 2008 (the most recent year that all ten sites were sampled) and are shown in Figure 52. Scores on the Tetbury Avon fall from around 7.4 at the top site to 6.6 on the main Avon below Malmesbury. This decrease in score is expected as the gradient of the river falls so the macroinvertebrate community contains fewer taxa adapted to high flow velocity. The same trend is not so clear on the Sherston Avon where the top two sites at Luckington Court and Crow Down Springs both have lower LIFE scores than further downstream. Possible reasons for this are discussed below.

The LIFE EQI for each site has been averaged for each year and the data plotted in Figure 52. The results in Figure 52 typically show LIFE EQI scores are greater than 'one' indicating that the community present is that predicted for such a river in an un-impacted state and therefore showing that the supported river flow is providing a healthy environment for macroinvertebrates. Sites where the annual average falls below one and therefore requiring more detailed consideration are:

- Crow Down Springs                      headwaters of the Stanbridge arm of the Sherston Avon
- U/s Luckington Court                  headwaters of the Luckington arm of the Sherston Avon
- Slads Farm                                headwaters of the Tetbury Avon
- Malmesbury d/s STW                  main Avon below Malmesbury

These sites are discussed in more detail below:

### Crow Down

The Crow Down Springs site is just downstream of the least frequently used stream support point (between 1999 and 2009 only used in 2003) and low EQI values were recorded in 2002, 2004 and 2006. The lowest LIFE EQI of 0.94 was recorded in spring 2004. The Stanbridge stream support was used heavily in 2003 to fully test the stream support water supply and this may be expected to increase the LIFE score in the following year. However, it may be that the low dissolved oxygen of the stream support water, that is discharged less than 100m upstream of the sample site, resulted in a reduction in the LIFE score. This would also explain a low ASPT score in spring 2004 as both LIFE and BMWP scoring systems are likely to be affected by low dissolved oxygen levels. The most recent sample from spring 2008 recorded a LIFE EQI of 1.02 indicating that this is not a downward trend.

An investigation into the effects of stream support on water quality by the NRA in 1995 (National River Authority 1995a) concluded that stream support at Stanbridge significantly reduced dissolved oxygen levels at the discharge point but that little or no effect was recorded one kilometre downstream. It appears therefore that the sample site is within the zone affected by the stream support but that the impact is relatively minor and localised.

## Luckington Court

Samples from Luckington Court are more consistently 'low' than at Crow Down springs and this may be related to the site being 500m downstream of the perennial head and the spring water being naturally low in dissolved oxygen. The Environment Agency have recorded low dissolved oxygen at this site during routine surveys and the NRA investigation in 1995 (National River Authority 1995a) and it is likely that this is at least partly responsible for the low LIFE score recorded at this site.

Samples from the site contain a diverse range of macroinvertebrate that require high current velocity to survive such as freshwater shrimp, riffle beetles and black fly larvae and it is not thought that the community is limited by low flows.

## Slads Farm

The Slads Farm site is 500m downstream of Tetbury Sewage Treatment Works and, therefore, there is the possibility of a detectable impact in water quality. When results in Appendix L2 are examined it can be seen that most of the low LIFE EQIs in 1995, 1999, 2000 and 2002 correspond to low ASPT EQIs. This suggests that the low LIFE EQIs may be due to the absence of taxa sensitive to organic pollution that are also high LIFE scorers. This results in a low LIFE score.

## Main Avon - Malmesbury d/s STW and Great Somerford

Both sites had low LIFE EQI scores in 2004 and 2006 even though in 2001, 2002 and spring 2008 the results were all 1.0 or higher. The lower LIFE scores in 2004 and 2006 could be a response to the lower flows recorded in this period. The higher EQIs in spring 2008 indicate a recovery following the wetter period that started in the winter of 2006/7. Samples taken in recent years from d/s Malmesbury STW have consistently produced EQI values of above 1.0.

## White-clawed crayfish

White-clawed crayfish are included in the above macroinvertebrate scoring system but more importantly this is an increasingly threatened species for which a lot of work has been undertaken. This includes the restocking of the Sherston and Tetbury Avon following extinction of the population from crayfish plague in the 1980s (Frayling & Spink 1998). No specific flow targets have been set for the white-clawed crayfish as it is found in lakes and canals as well as shallow riffles. In flowing water they may be found associated with:

- Undermined, overhanging banks.
- Sections exhibiting heterogenous flow patterns with refuges.
- Under cobbles (juveniles) and rocks in riffles, and under larger rocks in pools.
- Among roots of vegetation, accumulations of fallen leaves and boulder weirs.
- Under water-saturated logs.

The LIFE scores indicate that there is suitable flow for the macroinvertebrate community in the area where white-clawed crayfish are found. It is unlikely that any of the habitats listed above will be limited by inadequate flow.

### **5.5.3 Results of ecological assessment – fish**

This section covers the ecological flow requirements of fish in the Malmesbury Avon. The relationship between flow and angling quality is covered in Section 5.5.5.

Fish communities of the Malmesbury Avon can be divided between those present in the tributaries and those present in the main Avon below Malmesbury and in the Tetbury and Sherston Avon in the immediate vicinity of Malmesbury. Flow conditions in the former are suited to brown trout, bullhead and stone loach and in the latter coarse fish such as roach and chub that prefer slower current velocities. These two categories are considered below

Restoring Sustainable Abstraction – Malmesbury Avon

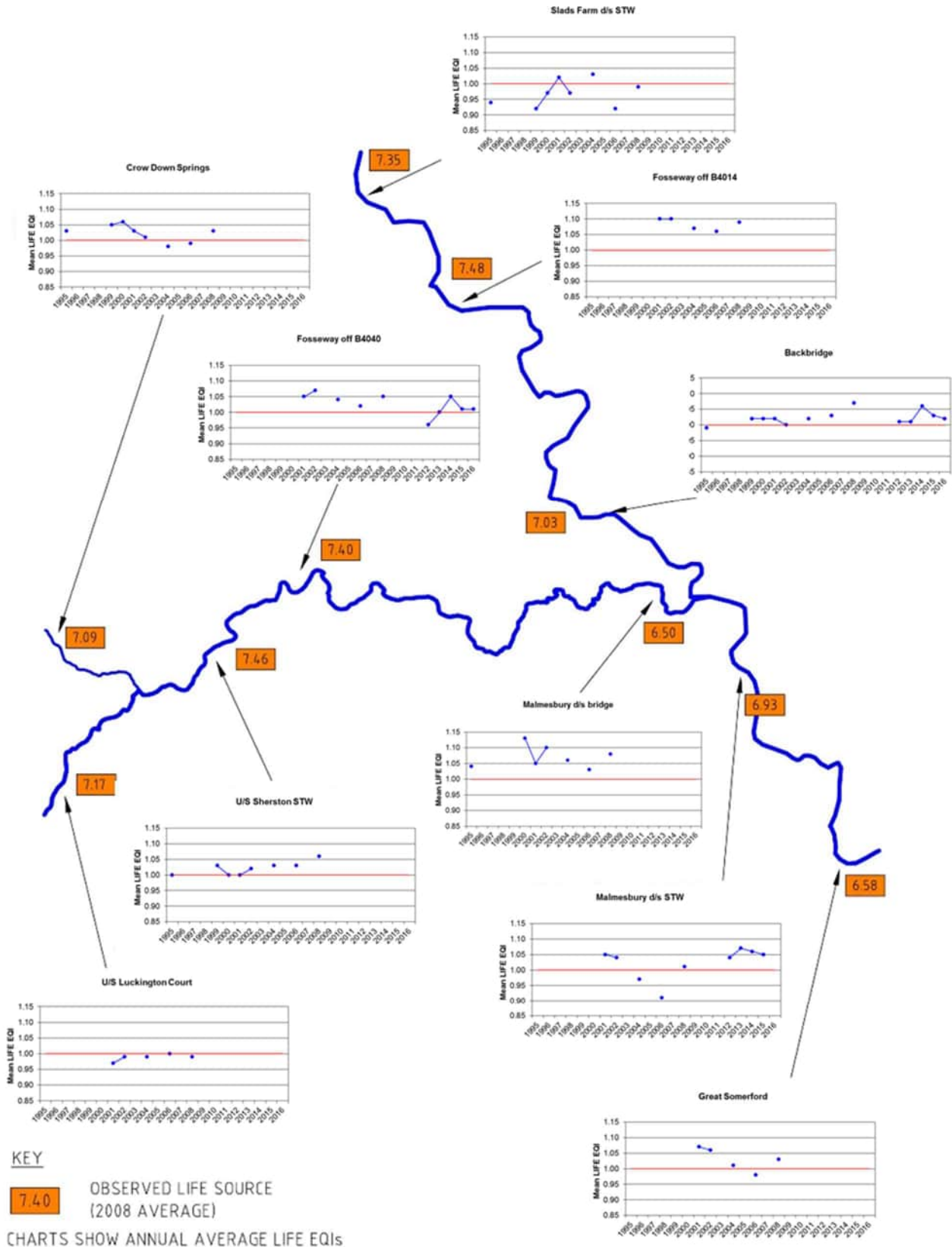


Figure 52 Average LIFE scores in 2004 and annual average LIFE EQIs

## Malmesbury Avon tributaries

In the upper and middle reaches of the Tetbury and Sherston Avon and in other tributaries such as the Woodbridge Brook, Gauze Brook and Rodbourne Brook conditions are suited for wild brown trout, bullhead and stone loach. Brown trout are known to spawn in both the Sherston and Tetbury Avon and in the Woodbridge Brook. A brown trout juvenile survey by the Environment Agency in 1995 on the Sherston Avon showed that suitable spawning and nursery areas are mainly found in the upper reaches of the river but are sparse on the lower section at least partly due to the lower gradient, clay substrate and impounded sections (National Rivers Authority 1995b). Results of electric fishing surveys between 1999 and 2004 support this with trout fry mostly being found in the upper section of the Sherston Avon see Appendix L4. Electric fishing surveys on the Tetbury Avon suggest that a similar situation exists with trout fry only being found upstream of Backbridge. No trout or bullhead were found in a 2004 survey at Slads Farm and it is thought that the lake at Shipton may prevent these fish colonising this reach.

Several angling syndicates manage the Sherston and Tetbury Avon as trout fisheries. Supplementary stocking of brown trout is frequently carried out and this can confuse the results from electric fishing surveys, however, the presence of trout fry shows that trout spawn in the area and that a self-supporting population exists. The upper reaches of both the Sherston and the Tetbury Avon are therefore receiving sufficient flow to support a wild trout population as well as the associated bullhead, stone loach and minnows that share the same habitat.

## Lower reaches of tributaries and Main Avon below Malmesbury

In this reach the river has the characteristics of a slow flowing clay substrate river dominated by coarse fish. These fish range from those associated with fairly high current velocities such as barbel and those preferring slower velocities such as roach. Brown and rainbow trout are stocked by angling clubs in this stretch. The diversity of flow types existing in this stretch of river means that there is some suitable habitat for all the above species to exist.

The operation of stream support is unlikely to have a significant effect on the spawning of coarse fish as spawning occurs in spring and early summer when flows are typically above the targets requiring the operation of stream support. Fry survival is related to the amount of cover available and flow is only likely to become limiting in extreme conditions when fish become crowded in pools leading to increased predation. Stream support prevents extreme low flow conditions that may otherwise be detrimental to the fish population.

River habitat improvement work such as the introduction of current deflectors and gravel riffles and erection of stock fencing has been undertaken on the Malmesbury Avon. Research into the effect of this work was carried out by Nick Giles & Associates and The Game Conservancy Trust and reported in 1999 (Giles 1999). The results of the work were encouraging with improved coarse and game fish densities recorded on the experimental reaches.

### 5.5.4 Results of ecological assessment – macrophytes

#### Recent Monitoring Sites

The results of surveys 2002-2008 are shown in Appendix L5 with a summary of findings from the historical sites in Appendix L6 including the percentage cover recorded for each species. The Macrophyte Flow Rank (MFR) has also been calculated for each survey and averaged to give an MFR value for each site. These MFR values are shown in Table 14 along with the Current Ecological Rating (CER) that has been derived by comparing the MFR with the 'expected' MFR (Appendix L).

The CER obtained for each of the ten monitoring sites is generally 'Slightly changed' from the benchmark. This suggests that the plant community is experiencing slightly lower flow velocities than would be expected naturally for the types of rivers described. However, it is noted that due to the quite low number of MFR scoring taxa generally recorded (usually only 5-10), only a moderate degree of confidence should be associated with most of the results. Also factors such as pollution, river management, disturbance and shading have impacts on the plant community that are difficult to separate from insufficient flow.

Table 14 Results of Macrophyte Flow Rank Assessment

Site	MFR	CER (change from benchmark)	Confidence (based on number of taxa)
Luckington Court	2.26	Slightly changed	Moderate
Crow Down Springs	2.24	Slightly changed	Moderate
U/s Sherston STW	2.09	Slightly changed	Moderate
Fosseway off B4040	2.20	Slightly changed	Moderate-High
Malmesbury d/s bridge	1.33	Moderately changed	Low-moderate
Slads Farm	1.99	Moderately changed	Moderate
Fosseway off B4014	1.99	Moderately changed	Moderate
Backbridge	2.26	Slightly changed	Moderate
D/s Malmesbury STW	1.74	Slightly changed	Moderate-high
Great Somerford	1.70	Slightly changed	Low-moderate

The two upper sites on the Tebury Avon (Slads Farm and Fosseway off B4014) recorded a CER of 2 (moderately changed from benchmark conditions). The MFR of 1.99 at both sites was just below the cut-off (2.0). Tetbury STW is just upstream of the Slads Farm site and this will affect the plant communities downstream by increasing the nutrient levels and may account for the slightly lower than expected scores. A low level of confidence is assigned to the assessment when other factors (e.g. pollution and eutrophication) are likely to be significant.

The only other site where a CER of 2 was obtained was Malmesbury d/s bridge. This is a deep impounded section of river with no appreciable current and would therefore be expected to have a low MFR. The impounded nature makes this a poor reach on which to judge the suitability of flow targets.

### Historic Monitoring Sites

The survey results and the community type calculated for each survey are provided in Appendix L7 with a summary of findings provided in Appendix L. Holmes (Holmes 1996) concluded from his macrophyte surveys 1992-95, that the whole of the upper catchment of this part of the Bristol Avon did not show any signs of having suffered from depleted flows following the drought of the early 1990s based on the evidence of the plant communities.

The communities at all sites typically reflected the physical structure noted for each. All sites were experiencing perennial flow, nevertheless some were classified as ditch types often as a reflection of the physical conditions present, or winterbourne types due to the presence of a small amount of non-aquatic herbs and grasses. The sites were re-surveyed in 2001 with generally similar findings. Any changes could not really be associated with a changing flow regime and were more likely due to slight changes in the locations surveyed.

### Other Macrophyte Studies

A review of macrophytes in the Malmesbury Avon undertaken by Loughborough University in 1993 (Wade & Cranston 1993) concluded that there was some evidence of a change in floral composition since the earliest records of 1957, these changes being:

- Marginal and emergent vegetation appeared to be increasing and encroaching on the channel.
- The spread of *Sparganium emersum*, *Sagittaria sagittifolia* and *Nuphar lutea* upstream from Malmesbury
- A decrease in *Ranunculus*, *Oenanthe fluviatilis* and *Berula erecta*
- Encroachment of *Potamogeton crispus* into this community type

The main changes associated with the river that may have accounted for the above were considered to be water quantity, weed cutting and other maintenance and a reduction in tree cover. The review did not recommend any minimum flow requirements to maintain the appropriate macrophyte community in the Malmesbury Avon.

### Blanket weed survey

Survey results are shown in Table 15. It is very difficult to draw any firm conclusions from the results of this survey. The *Enteromorpha* recorded on the Tetbury Avon at Abbey Weir is possibly what gave rise to most concerns previously. It is generally higher in the first survey of each year than the second and this could be related to sunshine/day length. Higher levels of sunshine will increase the photosynthetic rate of the *Enteromorpha* resulting in greater buoyancy and therefore greater likelihood of appearing at the surface. The only year where it was recorded at higher levels in the second survey was 2003 when it was very hot and sunny in the late summer and autumn. The overall level of benthic *Cladophora/Vaucheria/Diatom* is generally higher in the first than second survey of the year. In 2003 the percentage cover does not reduce as much later in the year and at some sites increases significantly. To improve the hydrogeological understanding of the system the stream support was run at a higher rate than required to meet the flow targets in 2003. Even though this resulted in a relatively high level of low nutrient stream support water the blanket weed flourished through the summer and autumn at many sites. This would indicate that it may have been the extended hot and sunny summer/autumn in 2003 that had a greater influence on blanket weed growth than the flow received.

High current velocity is only likely to restrict the growth of *Cladophora* if it destabilises the substrate resulting in fresh growth being worn off moving substrate. Otherwise it has been found to thrive in turbulent conditions (Ibbotson & Welton 2000) in riffle habitats and on concrete channels in currents >1 m/s, much higher than found on much of the Malmesbury Avon. While increased flow may have a small effect by increasing water depth and thus reducing light intensity and by diluting nutrients it is unlikely that increased flow alone will result in a significant reduction in blanket weed levels. Of the different forms of blanket weed recorded, *Enteromorpha* is most likely to be reduced by an increase in flow velocity. However, as it only appears in impounded sections such as above Abbey Weir on the Tetbury Avon then the very small increase in current provided by stream support is unlikely to have a significant effect.

Table 15 Blanket weed survey results showing percentage cover at each site

Site	2002		2003		2004		2005		2006		2008	
	Jul	Oct	May	Sep	Jun	Oct	Jun	Oct	Jun	Oct	Jun	Oct
<b>Stanbridge</b> ST 842 861	40	-	30	10	20	5	0	70 <b>D</b>	-	5 <b>C</b> 5 <b>D</b>	5 <b>V</b> 5 <b>D</b>	10 <b>D</b>
<b>Luckington Brook</b> ST 836 835	1	1	30	70	30	5	0	5 <b>C</b> 5 <b>D</b>	15 <b>C</b>	3 <b>C</b>	-	-
<b>Sherston Bridge</b> ST 853 856	80	5	30	5	80	1	20 <b>C</b>	0	85 <b>C</b>	20	0	5 <b>D</b>
<b>Pinkney Bridge</b> ST 866 868	80	10	50	60	60	10	100 <b>V</b>	90 <b>D</b>	30 <b>V</b>	25 <b>V</b>	10 <b>V</b>	80 <b>V</b>
<b>Easton Grey</b> ST 881 874	95	2	90	30	60	10	80 <b>V</b>	40 <b>D</b> 5 <b>V</b>	70 <b>V</b>	85 <b>V</b>	50 <b>D</b>	70 <b>V</b>
<b>Cowage Fm</b> ST 903 863	80	-	-	90	80	5	30 <b>C</b>	100 <b>D</b>	40 <b>C</b>	0	0	30 <b>D</b>
<b>Silk Mills</b> ST 936 871	-	-	75	80	80	40	15	40 <b>C</b>	15	5 <b>C</b>	10 <b>V</b> 10 <b>C</b>	0
<b>Long Newnton</b> ST 911 913	-	-	-	-	70	5	0	0	30	0	90 <b>V</b>	40 <b>C</b>
<b>Brokenborough</b> ST 914 893	-	-	-	-	70	10	0	0	20	0	50 <b>V</b>	50 <b>V</b> 30 <b>D</b>
<b>Backbridge</b> ST 922 883	5	10	1	60	50	3	70	0	35	2 <b>C</b> 5 <b>D</b>	50 <b>D</b>	40 <b>V</b> 10 <b>D</b>
<b>Abbey Weir</b> ST 928 872	* 5 <b>E</b>	-	10% at edge	60 <b>C</b> 20 <b>E</b>	80 <b>C</b> 1 <b>E</b>	20	65 <b>C</b> 15 <b>E</b>	10 <b>C</b>	60 <b>C</b> 10 <b>E</b>	10 <b>C</b>	30 <b>C</b> 30 <b>E</b>	0
<b>Cowbridge</b> ST 943 863	90	-	-	5	5	-	0	30 <b>D</b>	5	-	-	5 <b>D</b>
<b>Great Somerford</b> ST 965 832	70	-	-	5	5	-	-	0	5	-	-	5 <b>D</b>

\* Too deep to see substrate

**C** = *Cladophora* **D** = Diatoms, **E** = Enteromorpha **V** = *Vaucheria*,

### Overall assessment of macrophyte survey results

In conclusion, the macrophyte community of the Malmesbury Avon is of a slightly poorer quality than that expected from such a river and this may indicate a reduced flow compared to the natural flow. However, as described earlier, the method of assessment is heavily influenced by physical channel modifications, impoundments, nutrient input from arable land and STWs and heavy shading. At least one of these factors probably affects the survey sites. Where conditions allow i.e. unshaded riffles or fast runs, there are large stands of water crowfoot on both the Sherston and Tetbury Avon in summer that are naturally succeeded by large stands of water cress in autumn, which is very similar to the findings on classic chalk streams. Further downstream a plant community containing water-lily and greater-rush exists as would be expected from an impounded lowland river.

### 5.5.5 Angling

Apart from providing pleasant scenery for ramblers in the area and limited use by canoeists, the main recreational use of the Malmesbury Avon is for angling. Both tributaries and the main river are fished for game and coarse fish by clubs, private syndicates and individuals. The Sherston and Tetbury Avon support populations of brown trout whilst in the reach between Malmesbury and Dauntsey, stocked brown and rainbow trout co-exist with coarse fish and grayling.

Low flows led to concerns that there was a reduction in the number of days when suitable conditions occur for trout fishing on this reach. Work undertaken by the Institute of Fisheries Ecology (IFE) attempted to link flow and angling quality at Great Somerford (Ibbotson and Welton, 2000). Three methods were used to link flow and trout angling quality. These were:

- A panel of expert anglers visiting the site on the same day to assess pre-selected transects at particular flows
- Walkover surveys of the complete site by local anglers on any day
- The assessment of video records, by a dummy panel, of selected transects at different flows

Perhaps unsurprisingly it was shown that angling quality declined at lower flows. The most successful approach was the assessment of video records by a panel. This demonstrated the presence of break points where further reductions in flow had sudden and severe effects on angling quality for trout fishing. More data were required to reduce the large standard error for the break points but it was cautioned that this may have identified more break points that would require even more data to confirm.

It was noted in the report that the natural fish population at Great Somerford would only support a 'coarse' fishery and that the natural recruitment of trout would not support a trout fishery. The report concluded that any further work would require the assessment of the relationship between coarse fish angling quality as well as for trout fly fishing. This work was reported in 2001.

After the long dry summer of 2003 local coarse anglers were consulted about their views on how river flows affected fishing quality. Bristol Amalgamated Anglers reported that no complaints had been received and a local angler thought that the low flows had led to a concentration of fish in pools making them easier to catch. While angling quality is not all about how easy it is to catch large numbers of fish, the general impression was that river flow was not a significant angling issue in 2003. A similar response was received in following enquiries made at the end of 2005, a year in which stream support was used only to maintain flow target, no excess abstraction as part of pumping trials were undertaken.

Fly fishing quality on the Tetbury Avon was affected by an algal bloom in May/June 2003. This was believed to be due to work carried out on the lake upstream resulting in the release of nutrients that triggered rapid algal growth. Flows at the time were above the target flow at Brokenborough but Tetbury stream support was turned on early to help flush away the algal bloom highlighting an additional benefit of stream support.

## 5.6 Summary

The maintenance of target river flow through Malmesbury since 1995 has produced an acceptable amenity flow. This flow supports a healthy river ecology. There are no water quality issues associated with the proposed increased stream support discharges.

## 6 Licence application

### 6.1 Introduction

Wessex Water abstractions for PWS and SS in the Malmesbury Avon Catchment are authorised under two licences. In this section, the current licence arrangements are described followed by details of the proposed licence changes.

### 6.2 Current abstraction arrangements

#### 6.2.1 PWS

A schematic layout of the Malmesbury Groundwater Scheme showing local demand and export is shown on Figure 53: summer situation, SS fully active.

The Malmesbury Groundwater Scheme PWS abstractions are authorised by two licences, see Table 16:

Table 16: Wessex Water Malmesbury Avon licences

Licence No.	Sources	Issue date
17/53/01/G/410	Charlton, Cowbridge, Hullavington, Lower Stanton St Quinton, Park Road, Rodbourne, Luckington, Stanbridge and Tetbury	25 Aug 1981
17/53/01/G/203	Milbourne	01 Aug 1981

Copies of the two licence documents are contained in Appendix M. The two licences are not linked. Details of the currently authorised daily and annual abstraction rates from the five PWS sources are detailed in Table 17 and Figure 53 (summer daily). Figure 53 also includes the Bristol Water abstraction. The licensed Wessex Water PWS take is constrained by the stream support usage and a group licence condition (17/53/01/G/410). In summary, the current licensed Wessex Water PWS abstraction is:

Winter 47.5 Ml/d and

Summer 39.1 Ml/d (5.7 Ml/d Milbourne and 33.4 Ml/d from the other five (PWS) sources).

#### 6.2.2 Stream Support

The licensed daily and annual abstraction totals for stream support, from the eight sources, are detailed in Table 17. The SS abstractions are authorised under licence 17/53/01/G/410.

The maximum daily SS abstraction rate is 26 Ml/d: 10 Ml/d from the Inferior Oolite aquifer and 17.5 Ml/d from the Great Oolite aquifer with a group limit of 26 Ml/d.

### 6.3 Application arrangements

The Milbourne licence allows abstraction from the Great Oolite. Whereas, the MGS licence (17/53/01/G/410) allows abstraction from nine sources (for PWS and SS): four from the Inferior Oolite and five from the Great Oolite.

It is understood that legally a licence should only authorise abstraction from one 'source of supply' e.g. only one aquifer. The Environment Agency has expressed a view that the Upper (Great Oolite) and Lower (Bridport Sand/Inferior Oolite) are two separate aquifers, hence different sources of supply. Therefore, as part of the licence change to restore sustainable abstraction the Environment Agency is likely to use the opportunity to implement administrative changes to ensure each licence only refers to one source of supply. Consequently, some points of abstraction will be moved to licence 203. This approach is summarised in Table 18 and used in Table 17.

Restoring Sustainable Abstraction – Malmesbury Avon

Table 17: Malmesbury Avon Wessex Water PWS and SS sources: current and proposed abstraction rates

Current Licence Arrangement					
Malmesbury Groundwater (17/53/01/G/410)					
PWS					
Source	Daily (SS off) MI	Daily (SS Active) MI	Annual (MI)		
Charlton	16.1	13.6	5800		
Park Rd	1.3	0	400		
Rodbourne	14.4	13	5200		
Cowbridge	10	7.5	3600		
<b>Total</b>	<b>41.8</b>	<b>34.1</b>	<b>15000</b>		
		but limited to	12460	(=34.1 MI/d)	
Summary					
	Daily (MI)	Annual (MI)			
PWS	41.8	12460			
SS	26	9490			
<b>Total</b>	<b>67.8</b>	<b>21950</b>			
But limited to	59.4	21650			
Therefore, if SS is fully active, the daily PWS is 33.4 MI/d (59.4-26)					
The All purpose condition imposes a 0.7 MI/d restriction on PWS (34.1-33.4)					
	Daily (MI)	Daily (SS active) MI	Daily (SS fully active) (MI)	Annual (MI)	
17/53/01/G/410	MGS	41.8	34.1	33.4	12460
17/53/01/G/203	Milbourne	5.7	5.7	5.7	2080
<b>Total (MGS+Milbourne)</b>	<b>47.5</b>	<b>39.8</b>	<b>39.1</b>	<b>14540</b>	
Stream Support					
Source	Daily (MI)	Annual (MI)	Comment		
Luckington	2.5	900			
Stanbridge	2.5	900			
Tetbury	2.5	900			
Hullavington	2.5	900			
LSSQ	2.5	900			
Charlton	2.5	900	In aggregate with PWS Total		
Park Rd	10	3600	In aggregate with PWS Total		
Cowbridge	2.5	900	In aggregate with PWS Total		
<b>Total</b>	<b>27.5</b>	<b>9900</b>			
But limited to	26	9490			
Proposed Arrangement					
Changes compared to current in Red					
PWS		On licence 203	Great Oolite		
All on licence 203		On licence 410	Inferior Oolite		
Source	Daily (MI) (with and without SS active)	Annual (MI)			
Charlton	13.6	4900			
Park Rd	0	0			
Rodbourne	13	4745			
Cowbridge	7.5	2737			
Milbourne	5.7	2080			
<b>Total</b>	<b>39.8</b>	<b>14462</b>			
But limited to	39.1	12775	(=35 MI/d)		
Summary - MGS (incorporating Milbourne)					
	Daily (MI)	Annual (MI)			
PWS	39.1	12775			
SS (GO)	5	1800			
SS (IO)	27.5	4200			
<b>Total</b>	<b>71.6</b>	<b>18775</b>			
Stream Support					
Source	Daily (MI)	Daily aggregate (MI)	Annual (MI)	Annual aggregate (MI)	
Luckington	10	18	3650		
Stanbridge	10		3650	3800	
Tetbury	7	-	2555		
Hullavington	2.5	-	400		
LSSQ	2.5	-	900		
Charlton	2.5	-	900		
Park Rd	0	-	0		
Cowbridge	0	-	0		
<b>Total</b>	<b>32.5*</b>				
* includes Luckington/Stanbridge aggregate					
No link to PWS annual					

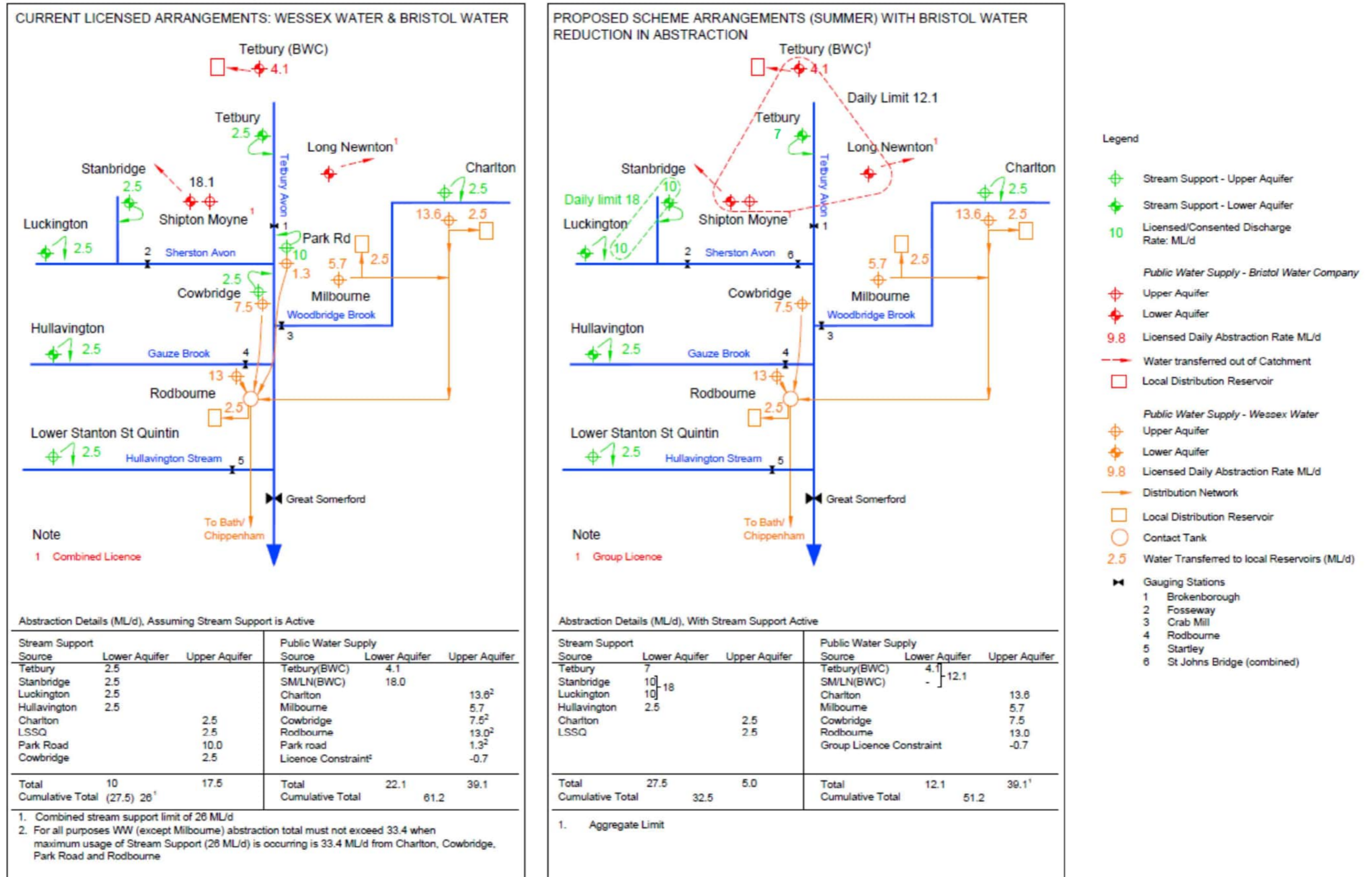


Table 18: Proposed split of sources between licences

Licence	Source of supply	Points of abstraction
17/53/01/G/410	Bridport Sand / Inferior Oolite	Hullavington Luckington Stanbridge Tetbury
17/53/01/G/203	Great Oolite	Charlton Cowbridge Lower Stanton St Quinton Milbourne Rodbourne

### 6.3.1 PWS

The following changes are proposed to the PWS component of the Licences;

- Revoke Park Road (1.3 MI/d);
- Reduce Cowbridge to 7.5 MI/d (from 10 MI/d), use controlled by an Operating Agreement;
- Reduce Rodbourne to 13 MI/d (from 14.4 MI/d);
- Remove Charlton peak PWS use when SS not active;
- Increase the number of boreholes to three from which abstraction is permitted at Rodbourne to maintain the integrity of the supply from this strategic source. Details to support this variation are contained in Appendix N.
- Reduce the annual PWS total to 12,775 (equivalent to 35 MI/d (from 39.8 MI/d));
- Daily PWS limit of 39.1 MI/d

#### Operating Agreement – Use of Cowbridge

As discussed in Section 3.3.7, uncertainty exist of the impact of Cowbridge upon flow in the lower reach of the Malmesbury Avon: Malmesbury to Great Somerford. Consequently, it is proposed to operate the Cowbridge source as the ‘last call to run’, meaning that the three other sources, are used to meet demand ahead of using Cowbridge. There is, however, a need to keep the supply main from Cowbridge to Rodbourne ready for use, so a regular low flow will be needed. In addition, the need to supply BW from Cowbridge when the Didmarton Water level is below the control curve (Section 4.5.4), will need to be incorporated in the Operating agreement. The wording for the Operating Agreement will be agreed between Wessex Water and the EA during the licence determination period.

### 6.3.2 Stream Support

The following changes are proposed to the SS component of the Licence:

- Revoke Park Road (Great Oolite) SS (10 MI/d): potentially reduces flows in the Sherston Avon which it does not support;
- Revoke Cowbridge (Great Oolite) SS (2.5 MI/d) – The discharge does not support the depleted reaches in Malmesbury; the abstraction probably exacerbates the situation in Malmesbury;
- Increase in Inferior Oolite stream support abstraction by 17.5 MI/d (from 7.5 to 25 MI/d) from Luckington, Stanbridge and Tetbury;
- New daily Luckington and Stanbridge aggregate limit of 18 MI/d;
- New annual stream support limit of 3800 MI from Luckington, Stanbridge and Tetbury
- Remove Group stream support limit.

The varied stream support abstractions will be operated to maintain the river flow targets as listed in Table 19.

Table 19: Malmesbury Avon Proposed prescribed flows and corresponding augmentation action

River	Gauging Point	Proposed licence pf (MI/d)	Action required to maintain pf
Tetbury Avon	Brokenborough	6.8	Switch on Tetbury at 2.5 MI/d, up to max. 7 MI/d
Sherston Avon	Fosseway	14 (Trigger)	Switch on Luckington at 2.5 MI/d
Sherston Avon	St Johns Bridge combined	7.2	Use Luckington and Stanbridge up to a combined maximum of 18 MI/d
Woodbridge Brook	Crabb Mill	2.50	Augment up to 2.50 MI/d from Charlton
Gauze Brook	Rodbourne	1.50	Augment up to 2.50 MI/d from Hullavington
Rodbourne Stream	Startley	1.00	Augment up to 2.50 from LSSQ <sup>1</sup>
Malmesbury Avon	Great Somerford	26.6 <sup>2</sup>	Augment up to 2.50 from Charlton Augment up to 2.50 from LSSQ

<sup>1</sup> LSSQ – Lower Stanton St Quinton

<sup>2</sup> based on recent re-rating (Section 2.5.2)

### 6.3.3 Bristol Water

For completeness and as the BW reduction provides the resource for stream support, the proposed BW licence changes are given here. The proposed licence comprises:

- The current two licences (Shipton Moyne/Long Newnton and Tetbury) to be grouped.
- Under this group licence the maximum daily abstraction will be 12.1 MI/d, with a sub group condition limiting the daily abstraction from Tetbury to 4.1 MI/d
- Above the Upper Control Curve: no restriction as to when 12.1 MI/d can be taken (no rolling average)
- Between the Upper and Lower Control Curves: a 30 day rolling average limit of 9.79 MI/d
- When restricted by the Lower Control Curve: the 30 day rolling average limit to be 8.29 MI/d
- The annual group licence total is 3,573 MI.

## 7 Conclusions

The overall conclusion of the work and results presented in this report, subject to two caveats, is:

**The implementation of the Memorandum of Understanding and other changes by Bristol Water, and the proposed variation to Wessex Water licences (subject of this report) restores sustainable abstraction and gives acceptable river flows along the Malmesbury Avon, through the climatic conditions experienced from 1970 to 2016.**

The overall conclusion is based on empirical findings, as the proposed licence variations have been in effective operation since July 1995, and on numerical modelling results which have confirmed the conceptual understanding.

The individual conclusions, from empirical and numerical assessments, that allow the overall conclusion to be made are:

- Increased Inferior Oolite stream support since July 1995 has maintained target river flows along the Malmesbury Avon, apart from August/September 2013.
- Under supported river flow conditions the river macroinvertebrate ecology does not show any stress due to 'low' flows.
- Under supported river flow conditions the river ecology is 'healthy' – the expected type and abundance of macroinvertebrate, macrophytes and fish for this type of river are present.
- Under supported river flow conditions an acceptable amenity flow has been achieved along the Malmesbury Avon.

Two points of uncertainty remain:

- 1) The impact on SS need from the Inferior Oolite aquifer if the PWS sources are used at full licence;
- 2) The influence of Cowbridge PWS abstraction on flow along the lower reach: Malmesbury to Great Somerford.

To address these uncertainties:

- 1) The Great Oolite model has sought to quantify this additional SS need to maintain target flows in Malmesbury, and these model outputs have been used to generate the SS need. The potential for additional leakage through Sherston is not addressed by the GO model. However, the pipeline transfer is the mitigation measure if more SS is needed than predicted, whereby BW reduce abstraction from the Inferior Oolite.
- 2) The flow accretion behaviour along this reach and how the Cowbridge source impact this is not fully understood. Therefore, as a precautionary measure Wessex Water proposes that Cowbridge is set as the 'last source to run' from the Malmesbury Groundwater Scheme, its use controlled via an Operating Agreement.

The principle factor in improving river flows has been the increased use of stream support abstractions from the Inferior Oolite aquifer. Analysis has identified that:

- Adequate Inferior Oolite water resources are available to meet the annual stream support demand (up to 4142 MI).
- The use of the Inferior Oolite aquifer is sustainable for stream support and PWS (at Shipton Moyne, Long Newton and Tetbury), i.e. no long-term decline in water level.
- A pipeline transfer, Wessex Water to Bristol Water, allows a reduction in Inferior Oolite aquifer abstraction in the event of very dry conditions to ensure protected rights are not derogated.
- The proposed SS licence variation and the Bristol Water PWS licence reduction, leads to net reduction in abstraction and hence will result in a net increase in flows from natural discharge points from the Inferior Oolite
- The residual environmental impacts of increasing Inferior Oolite stream support abstraction are considered to be environmentally acceptable.

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## APPENDIX A

### **Memorandum of Understanding**

## APPENDIX B

### **Statement of Intent**

## APPENDIX C

### **Statement of Intent Operating Agreement**

## APPENDIX D

### **Malmesbury Avon Bulletin**

## APPENDIX E

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## APPENDIX F

### **Revised Statement of Intent Operating Agreement**

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## APPENDIX N

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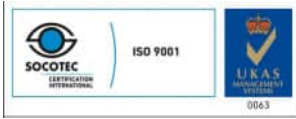
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# Malmesbury Community Flood Defence Scheme

Summary Optioneering Report

April 2020





## Quality Assurance

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## 1 Introduction

The town of Malmesbury in Wilshire has suffered from flooding twice recently in November 2012 and December 2013 as well as a more extreme event in July 1968 which affected the whole of the Bristol Avon catchment.

The Environment Agency commissioned their framework consultant JacksonHyder to carry out an appraisal study for a possible flood defence scheme for Malmesbury in 2017. As part of this study a new hydraulic model was developed and simulations carried out for recent high flow flood events which did not include November 2012. The reported model results showed limited agreement with measured level and rated flow data from the Environment Agency hydrometric gauges upstream and downstream of Malmesbury.

Using this model, JacksonHyder also carried out further model simulations using information supplied by the Malmesbury Flood Group to show the impact of the proposed scheme.

A review of this model was carried out in 2019 by Edenvale Young Associates on behalf of the Environment Agency as part of an inception study for a further proposed project to improve flood warning for Malmesbury. This was subcontracted through AECOM who are also Environment Agency framework consultants. The review identified several locations within the model where there was scope for improvement as well as to the underlying hydrology.

In September 2019, Edenvale Young Associates were commissioned via Malmesbury Town Council to implement a further version of the proposed community-led flood defence scheme and to carry out a simple cost benefit analysis to support development of an outline business case. This work required the Environment Agency flood model to be adapted and a range of flood events simulated in order to calculate the Average Annualised Damages.

## 2 Site Location

The location of Malmesbury at the confluence of the Sherston and Tetbury Avon is shown in Figure 2.1.

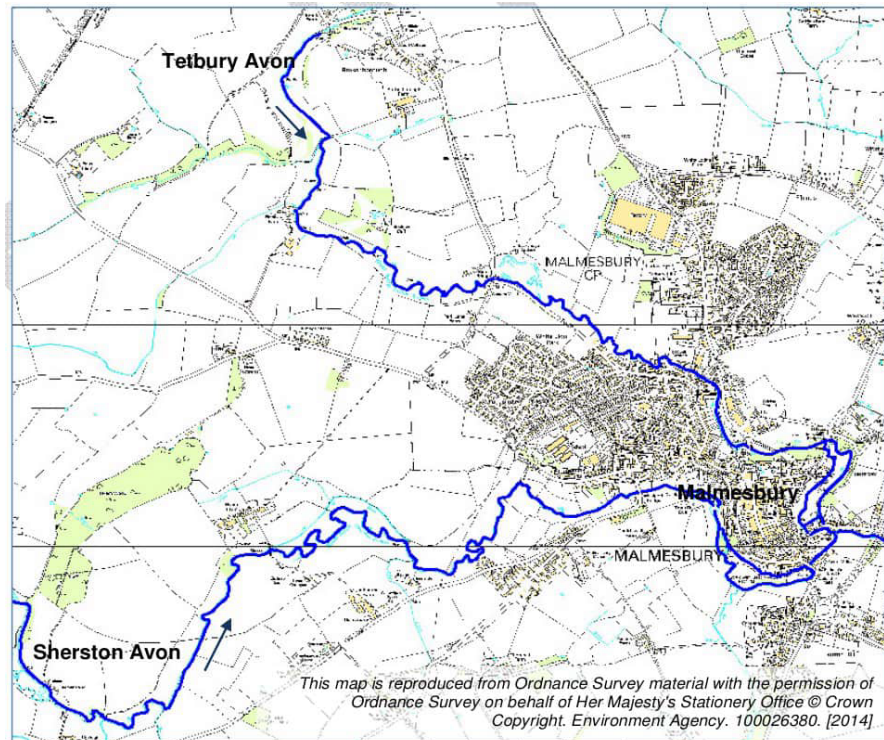


Figure 2.1: Extent of the River Avon in the study area, upstream of Malmesbury

The key area of interest in terms of property affected by the proposed community-led scheme is shown below in a downloaded map of the Environment Agency Flood Map for Planning.

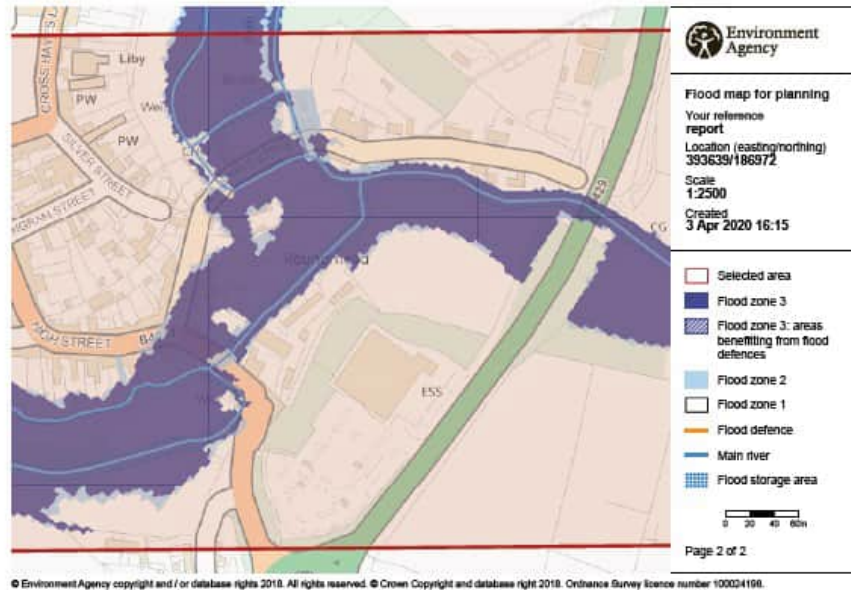


Figure 2.2: Area of Malmesbury affected by proposed community-led flood defence scheme, together with existing Environment Agency flood zones

Towards the south west of the above figure is the medieval St. John's Bridge shown below in Figure 2.3.



*Figure 2.3: St. John's Bridge*

### 3 Proposed Community Led Flood Defence Scheme

The preferred combination of options is comprised of two main elements and a number of minor enabling work as follows:

- Demountable defences across the Memorial Garden.
- Raising the existing wall along the Leat at the bottom of the gardens of the Lower High Street properties for approximately 70 metres.
- Provision of sumps to allow the emergency services to pump out seepage and overflows and a flood escape route.
- Provision of PLP.
- Moving the electricity pole and extending the EA flood relief channel plus lowering the raised bank under the A429 bridge.

The proposed measures are shown, hand annotated on Figure 3.1

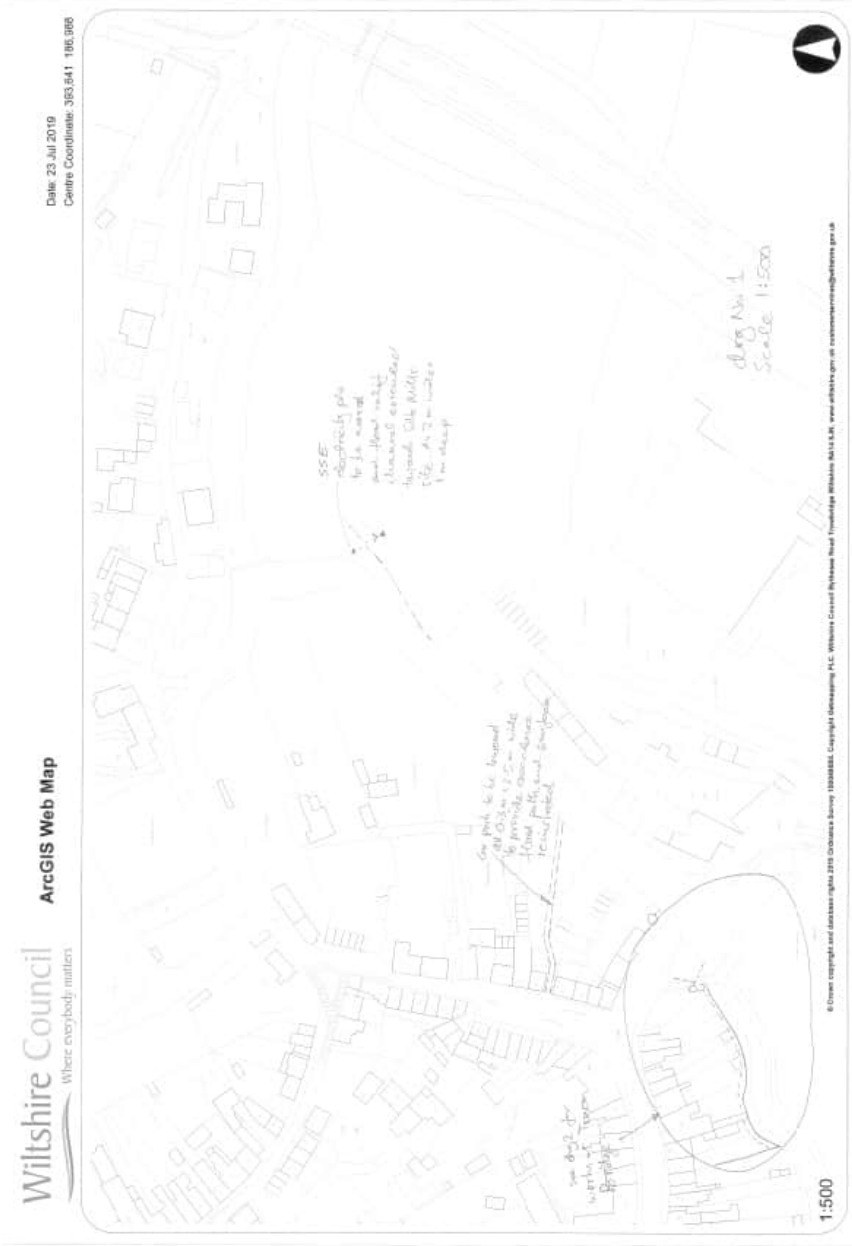


Figure 3.1: Hand annotated map showing locations of proposed works

The above map does not show the proposed works to reduce the right bank levels beneath the A429 road bridge.

## **4 Modelling Approach**

### **4.1 Existing Model**

The new hydraulic model for use in this study was based on the existing Environment Agency (EA) hydraulic model of the Upper Avon through Malmesbury developed by JacksonHyder in 2017 from a previous version developed by Capita in 2004.

A review of the hydrology and hydraulics undertaken as part of the JacksonHyder study was undertaken by Edenvale Young in 2019. This review identified that the reported results were subject to considerable uncertainty and further work was identified to reduce this uncertainty in order to develop a reliable flood warning service for Malmesbury.

One of the key issues with the existing model was that the road level at St. John's Bridge was not represented accurately and this was the first task to address in working with the model.

In order to generate reliable results for the current appraisal the existing model required substantial additional amendment and stabilisation which was not part of the project brief. Owing to the lack of any budget to carry out this work from the Environment Agency, the work was undertaken at no cost by Edenvale Young.

Also not part of the current brief was any additional hydrological analysis but a single site analysis for the St. John's weir gauge was undertaken in order to anchor the model results to reality. A new rating relationship at the gauge was derived using the updated model in order to support this analysis.

### **4.2 Modelling Strategy**

The basic strategy adopted for the modelling work was as follows:

1. Correct and stabilise the existing model

2. Look up what return period using the JacksonHyder hydrology correlates to the measured peak level at St. John's weir gauging station for the November 2012 event as this was the target event for which the community led scheme had been designed.
3. Calibrate and verify a new rating relationship at St. John's weir using the updated model
4. Develop an AMAX flow series for the St. John's weir gauge.
5. Undertake a single site hydrological analysis using the AMAX flow series to provide a second estimate on the T year return period peak flows at St. John's weir.
6. Consider the two sources of peak flow estimates against historical flood data available from the Malmesbury Flood Group and adjust return periods if required.
7. Develop a "do nothing" condition for each return period by consideration of bridge blockage scenarios.
8. Develop a version of the model for the "do something" case, using information provided by the Malmesbury Flood Group.
9. Calculate flood damages for each scenario using model results for the adjusted return periods using the facility in the Flood Modeller software.

### 4.3 Updates to existing model

As noted above, updates were made to the existing EA model particularly in the location of the proposed works.

The key corrections were as follows:

- removal of the zshape that artificially reduced the road level at St. John's Bridge
- removal of the "stability patch" in the St. John's Bridge location.
- replacement of the ISIS/Flood Modeller SPILL units upstream of St. John's Bridge and replacement with energy loss units,

- correction of chainages between cross sections.
- stabilisation of the model,

#### 4.4 Simulation of Options

As discussed above in Section 3, the following options were simulated using the new model.

**Option 1:** Current conditions (do minimum condition).

**Option 2:** Do nothing condition

This option involved the imposition of 75% blockage at both St. John's Bridge and the A429 road bridge.

**Option 3:** Do something condition

The do something option involved the implementation in the model of the proposed works discussed above in Section 3.

## 5 Hydraulic Modelling Results

Figures 5.1 and 5.2 below show 1 in 20 and 1 in 50 year return period level hydrographs from the JacksonHyder model and the updated model for the upstream and downstream extents of the proposed flood wall upstream of St. John's Bridge.

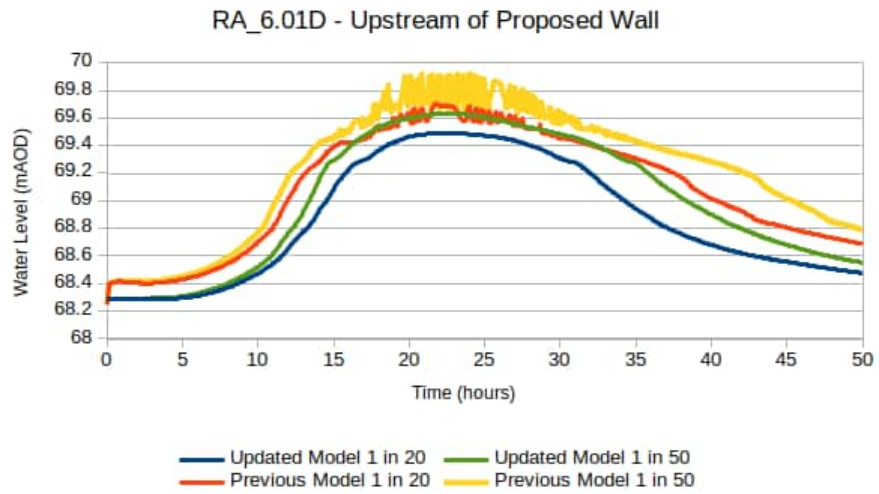


Figure 5.1: 1 in 20 and 1 in 50 year return period level hydrographs from the JacksonHyder and updated model at the upstream extent of the proposed flood wall

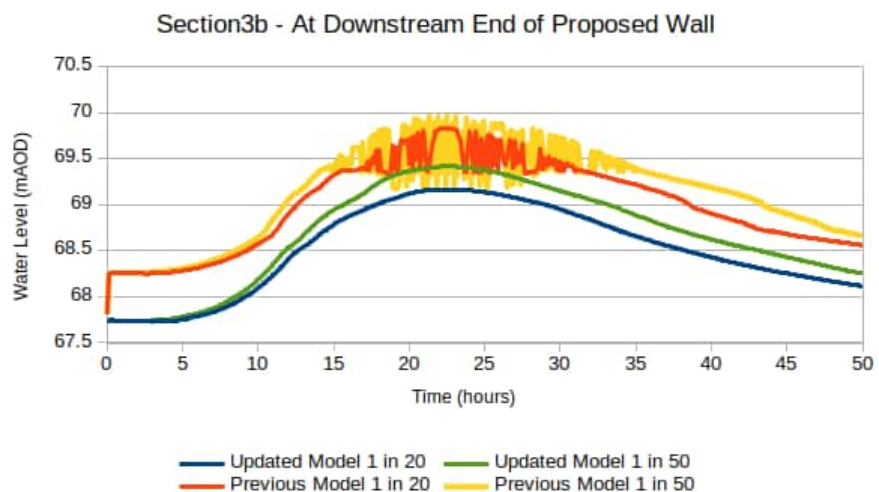


Figure 5.2: 1 in 20 and 1 in 50 year return period level hydrographs from the JacksonHyder and updated model at the downstream extent of the proposed flood wall

The above figures clearly show both the reduction in modelled water levels and the improvement in stability in the updated model.

Figures 5.3 and 5.4 show the change in flood extents between the JacksonHyder model and the updated model.

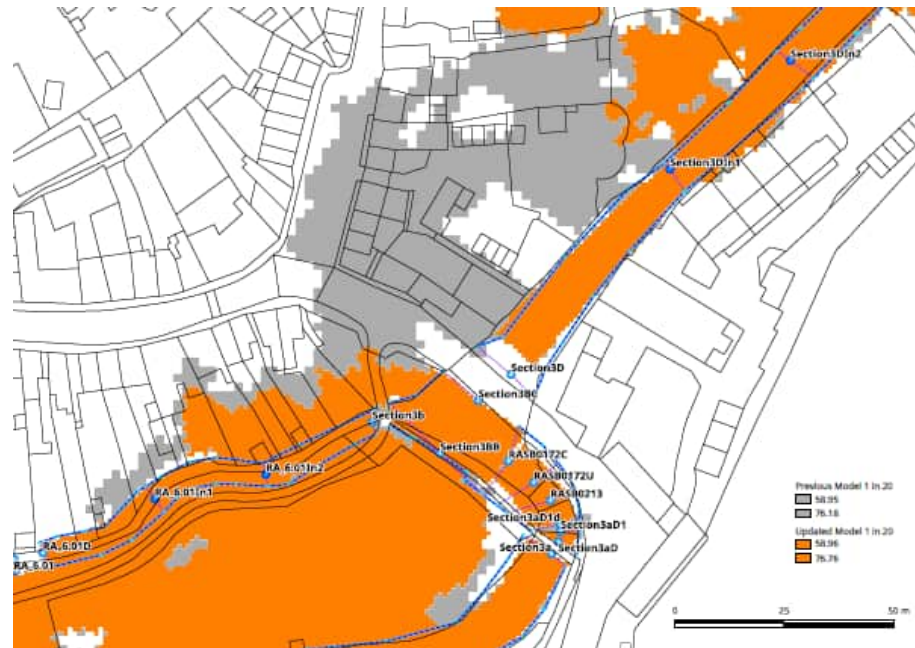


Figure 5.3: Comparison of 1 in 20 year return period flood extent from JacksonHyder and updated model

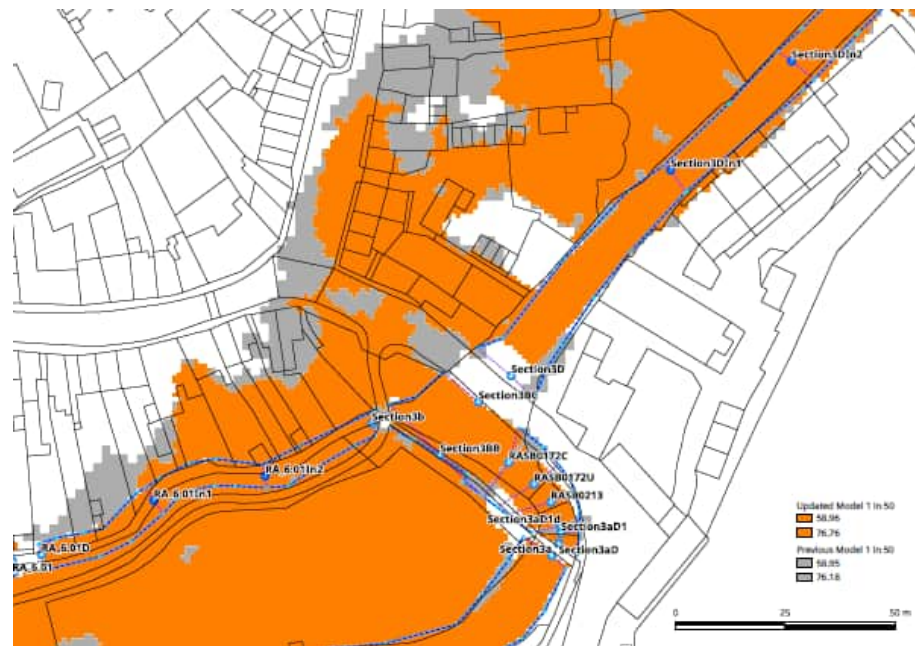
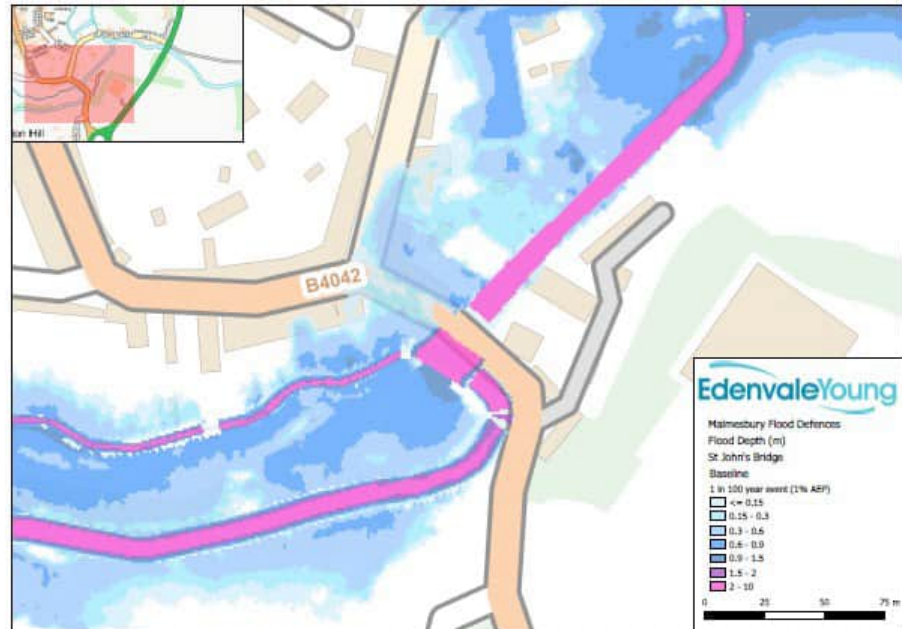


Figure 5.4: Comparison of 1 in 50 year return period flood extent from JacksonHyder and updated model

The 1 in 100 year return period flood extent from the updated model is shown below in Figure 5.5.



*Figure 5.5: 1 in 100 year return period flood depth map from the updated model*

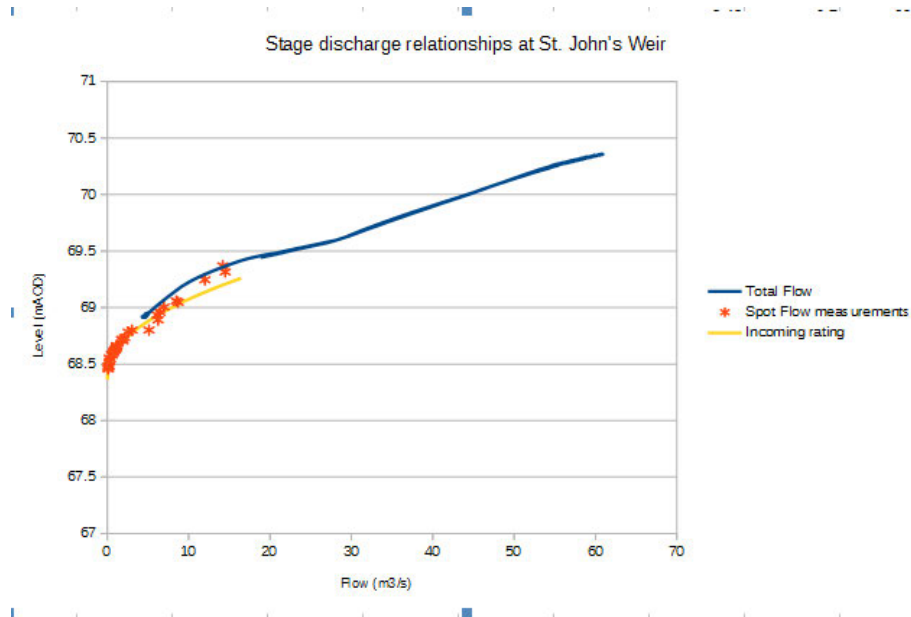
The modelled peak water levels from the T year return period simulations were compared with the recorded peak level of 69.84mAOD at St. John's Weir gauging station and it was determined that the modelled peak flood level from the 1 in 100 year return period simulation exactly matched the peak level from the November 2012 flood event.

Subsequent discussions Mr. EP Evans of the Malmesbury Flood Group cast doubt on the return period of the November 2012 event being 1 in 100 years, partly due to there having been a more extensive flood in Malmesbury in July 1968 and also that the following year (December 2013) saw a flood of almost equivalent magnitude at St. John's Weir gauging station.

As a result of the above, it was decided to undertake a single site hydrological analysis for the St. John's Weir gauge which required the development of a new rating relationship at the gauge.

## 5.1 St. John's Weir rating relationship

Figure 5.6 below shows a comparison between the stage/ flow relationship from the updated model, the historical spot flows and the rating relationship as supplied during the Malmesbury Flood Warning Project Inception Study.



*Figure 5.6: Comparison of modelled rating from the updated model with historic spot flow gaugings and hydrometric rating as supplied*

The modelled flow in this case is a sum of the total flows upstream of St. John's Bridge. The good agreement with historic spot flow gaugings lends confidence to the updated model at this location.

The above rating relationship was used to convert the AMAX series of historic peak levels into an AMAX series of peak flows required to undertake a hydrological analysis.

## 6 Hydrology

An FEH Single Site Analysis was undertaken for St. John's weir, Malmesbury. As this gauging site is not included in the HiFlows dataset, the data had to be applied to the WINFAP4 software manually.

## 6.1 Generation of a the AMAX series at St. John's weir

Version v32-A of the hydraulic modelled was used to determine a stage-discharge relationship at St. John's weir. Within the model, a 2d\_PO line was applied across the extent of St. John's bridge in order to obtain 2d generated flow results. The model was run for a high return period. Level results at the weir (Section3a) were extracted as well as flow results from the 2d\_PO line and flows results at the corresponding 1d section (Section3bc). A datum of 68.36mAOD was assumed.

AMAX level results from water years 2001-2017 were obtained from the Environment Agency and used with the stage-discharge relationship to find the corresponding AMAX flow series.

*Table 6.1: Annual Maximum levels and flows at St. John's Weir.*

Water Year	Recorded Level at St John's Weir (mAOD)	Calculated Flow (m <sup>3</sup> /s) (using stage discharge relationship)
2001	68.91	4.67
2002	69.18	8.93
2003	68.91	4.67
2004	68.91	4.67
2005	69.03	6.38
2006	69.35	13.91
2007	69.26	11.03
2008	69.13	8.09
2009	69.03	6.29
2010	69.05	6.63
2011	69.02	6.08

2012	69.84	37.05
2013	69.53	23.83
2014	68.97	5.32
2015	69.15	8.36
2016	69.01	5.88
2017	69.18	9.07

## 6.2 Single Site Analysis

This AMAX flow series was added to a .AM file for use within the WINFAP4 software. This file, along with the associated file for the catchment at St. John's were were imported into WINFAP4 for assessment. The station fitting for this gauge were found to be the following:

*Table 6.2: Single Site and Enhanced Single Site Station fittings for St. John's Weir and associated peak flow estimates. The \* indicates that the target return period > record length.*

Return Period	GL-LMED (growth curve factor)	Single Site Analysis Peak flow estimate (m <sup>3</sup> /s) (assuming QMED of 6.63 m <sup>3</sup> /s)	Enhanced Single Analysis Peak flow estimate (m <sup>3</sup> /s) (assuming QMED of 6.63 m <sup>3</sup> /s)	Previous JacksonHyder Peak flow estimate (m <sup>3</sup> /s) (node Sh09)
2	1	6.63	6.63	11.53
5	1.59	10.51	9.89	16.08
10	2.23	14.78	12.33	19.41
25*	3.56	23.59	15.92	-
50*	5.15	34.11	19.08	28.42
100*	7.52	49.85	22.72	33.18
200*	11.09	73.5	26.95	38.62
500*	18.71	124	33.62	-

1000*	27.94	185.12	39.63	57.28
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It must be emphasised that a single site hydrological analysis is technically valid for calculation of flood return periods up to half of the duration of the AMAX series record, so approximately 1 in 10 years.

Of some concern from the above table is that the Enhanced Single Site analysis indicates a return period of approximately 1 in 500 years for the November 2012 event which suggests an issue with the underlying methodology or software.

A converse relationship is presented in Table 6.2 below where the JH return period flows are correlated with the equivalent return period flows from the single site analysis.

*Table 6.3: JacksonHyder flood return periods and flows correlated with those from the single site analysis*

Return Period (years)	Modelled Flow (m <sup>3</sup> /s)	Single Site Analysis Return Period (years)
5	16.61	13
10	20.30	19
20	24.52	27
30	26.98	32
50	30.72	41
75	33.19	47
100	35.79	54
200	41.10	70
1000	60.79	143

From the above table it can be seen that the November 2012 flood event was a 1 in 54 year return period for the single site analysis compared to the 1 in 100 year return period from the JacksonHyder hydrology.

### 6.3 Historical context

There is a long history of flooding in the town of Malmesbury and the information below, dating from 1880 is reproduced from the JacksonHyder report of 2017.

*Table 6.4: Details of historical flood events in Malmesbury*

Date	Description	Data source
1880, 1882, 1916, August 1917, 1924	-	██████████ (2014, pers. comm.)
January 1925	-	Lewin, Fryer and Partners (2002) and the Environment Agency's Recorded Flood Outlines
December 1925	Railway Hotel, Duke of York and Gasworks affected	██████████ (2014, pers. comm.)
1928, November 1929, 1931	-	
1-3 May 1932	-	Lewin, Fryer and Partners (2002) and the Environment Agency's Recorded Flood Outlines
1946	-	██████████ (2014, pers. comm.)
1947	17 houses near Town Bridge affected	
1954	Duke of York and St. John's Street	
December 1959	-	
1960	-	Lewin, Fryer and Partners (2002) and the Environment Agency's Recorded Flood Outlines
November 1963	-	██████████ (2014, pers. comm.)
15-18 December 1965	-	Lewin, Fryer and Partners (2002) and the Environment Agency's Recorded Flood Outlines
1967	-	██████████ (2014, pers. comm.)
July 1968	30 houses in and around Lower High Street affected; flood fund opened	
1969	-	
February 1971	Heavy snow followed by incessant rain caused widespread flooding; football field "feet under water"	
1974	-	Lewin, Fryer and Partners (2002) and the Environment Agency's Recorded Flood Outlines
November 1977	Low lying gardens in Burnivale flooded	██████████ (2014, pers. comm.)
May 1979	Heavy rain floods 10 houses in Lower High Street including the Almshouses	
December 1979	Heavy rain, football field flooded but sandbags prevented damage in Lower High Street	
27-29 December	-	Lewin, Fryer and Partners

1979		(2002) and the Environment Agency's Recorded Flood Outlines
December 1985	During 48 hours over Christmas, 32 mm of rain was followed hours later by another 30 mm. Daniels Well flooded which caused some concern (first time it had happened) but prevention work "passed its strongest test with flying colours".	██████████ (2014, pers. comm.)
November & December 1992	Continuous heavy rain including 25 mm on 2 December – basements in Baskerville and St John's Street affected, one family had to be evacuated. Nurdens builders yard Park Road had 12" of water in the shop.	██████████ (2014, pers. comm.)
19-22 January 1999	Worst floods in living memory. Baskerville and St John's Street worst hit. Bowls Club and Football Club under water.	██████████ (2014, pers. comm.), Lewin, Fryer and Partners (2002) and the Environment Agency's Recorded Flood Outlines
30 October 2000	The River Avon and Tetbury Avon spilled out-of-bank, following heavy rainfall. The main damage was caused in St. John's Street, where a number of houses were flooded, and in the Park Road area. Several roads in other areas of the town were also under water, including Holloway and Swindon Road where they cross the river.	<a href="http://www.eilmer.co.uk/malmesbury/floods.htm">http://www.eilmer.co.uk/malmesbury/floods.htm</a>
October 2002	A Flood Reconnaissance Survey, undertaken by the Environment Agency on 8 November 2002, revealed the worst hit areas to be properties on St John's Street and Wynyard Mill, where flooding occurred from both the River Avon and mill streams. Flooding at Holloway Bridge also took place, with floodwater flowing down the road affecting a number of properties. Upstream of Stainsbridge was also affected, especially around the football club and adjacent properties.	Capita (2004)
January 2003	The River Avon spilled out-of-bank in Malmesbury and residents barricaded their homes with	Capita (2004)

	sandbags.	
10 January 2007	Photographs show various locations across Malmesbury affected by flooding, including St. Aldhelm Mead Park, Malmesbury Bowls Club and Baskerville.	<a href="http://www.bbc.co.uk/wiltshire/content/image_galleries/jan_2007_floods_gallery.shtml?1">http://www.bbc.co.uk/wiltshire/content/image_galleries/jan_2007_floods_gallery.shtml?1</a>
20 July 2007	-	The Environment Agency's Recorded Flood Outlines
25 November 2012	Four people had to be rescued by fire fighters from two homes after heavy rain led to flooding. Local residents were taken by surprise by how quickly the water rose. The mayor of Malmesbury said it was the worst flooding he had seen in the centre of the town for nearly 70 years. Part of High Street was cut off by waist-deep water, and roads in and out of the town were closed. St John's Street and some smaller streets were also affected. <b>Around 40 homes and businesses were flooded.</b>	<a href="http://www.bbc.co.uk/news/uk-england-wiltshire-20484386">http://www.bbc.co.uk/news/uk-england-wiltshire-20484386</a> <a href="http://www.bbc.co.uk/news/uk-england-wiltshire-20492483">http://www.bbc.co.uk/news/uk-england-wiltshire-20492483</a> Environment Agency (2013) <i>Malmesbury_Flood_Property_Report_2012.xlsx</i>
24 December 2013	<b>Eight properties were flooded in total.</b> Six properties in St John's Street were flooded not by water coming over the road by St. John's Bridge as in November 2012, but by water from downstream of St. John's Bridge coming up through floors and yards. One property was flooded in Lower High Street; other houses in the street only avoided flooding through the use of floodgates and, in one case, a pump.	██████████ member of the Malmesbury Flood Working Group

It was the view of the Malmesbury Flood Group that taking the above information into account and adopting a pragmatic view of flood return period estimation, that a return period for the November 2012 flood event of 1 in 40 years was reasonable subject a margin or error of approximately 10 years.

## 7 Optioneering results

Peak depth maps are shown below for the JacksonHyder(JH) 1 in 100 year and Single site (SS) 1 in 54 year return period simulations for the do nothing and do something scenarios.

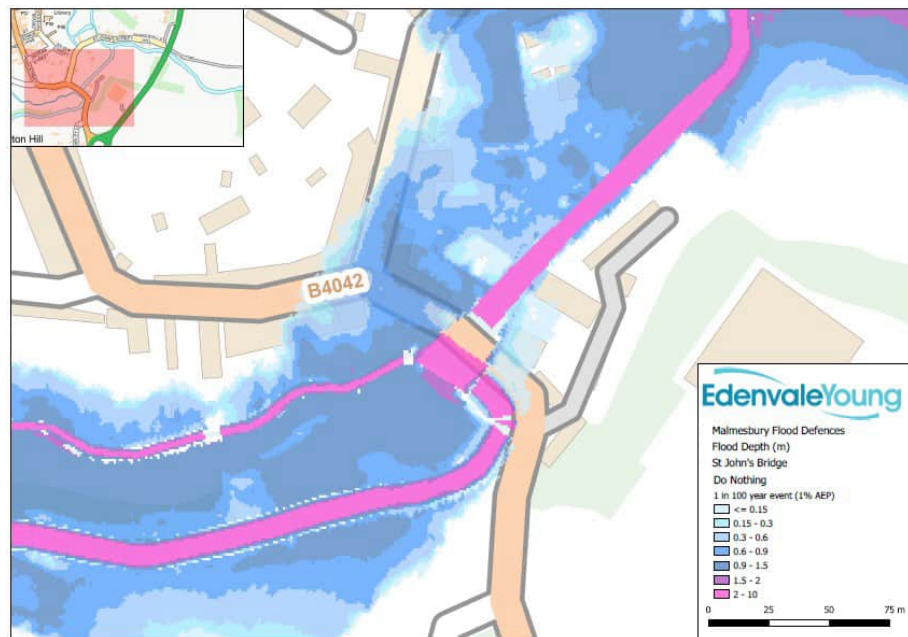


Figure 7.1: Peak flood depth map for the 1 in 54 year (JH 1 in 100 year) flood event do nothing scenario

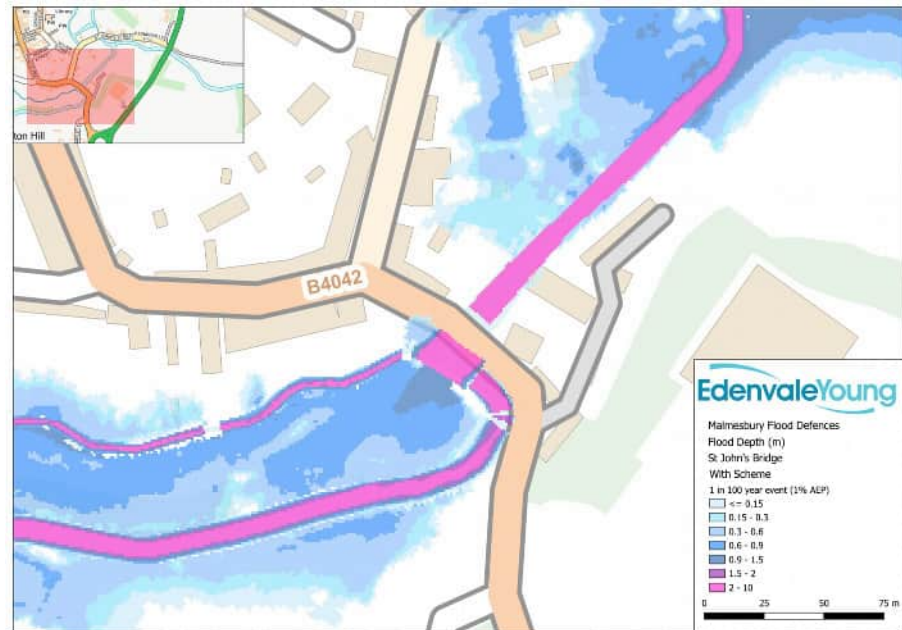


Figure 7.2: Peak flood depth map for the 1 in 54 year (JH 1 in 100 year) flood event do something scenario

The above maps are significant in that the JacksonHyder hydrology suggested that the November 2012 flood event was a 1 in a 1 in100 year event.

Difference maps have also been prepared showing the change in peak flood levels between the “with scheme” scenario and the baseline scenarios.

Figures 7.3 – 7.17 show these differences for the Jackson Hyder 1 in 20 year, 1 in 50 year, 1 in 100 year, 1 in 200 year and 1 in 1000 year return period scenarios at St. Johns Bridge, the Sherston/Tetbury Avon Confluence and the A429 road bridge locations. The captions on the figures however show the return periods from the single site analysis.

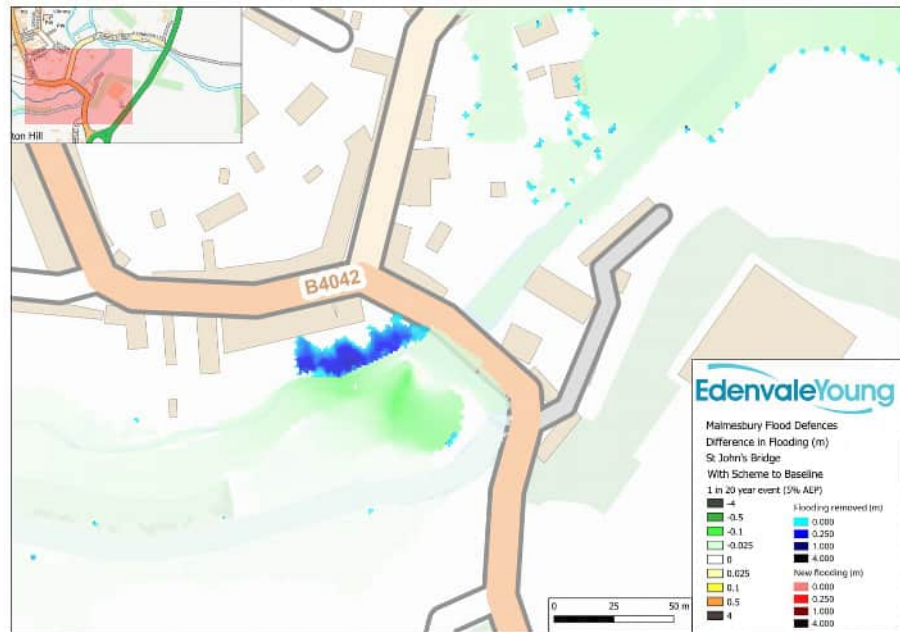


Figure 7.3: Peak Level Difference Map for 1 in 27 year return period flood event local to St. John's Bridge

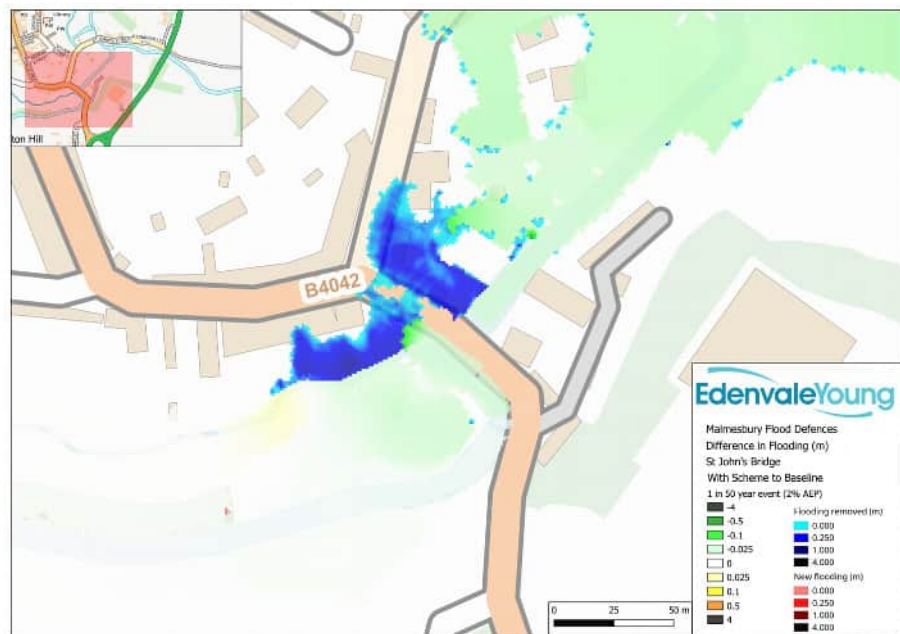


Figure 7.4: Peak Level Difference Map for 1 in 41 year return period flood event local to St. John's Bridge

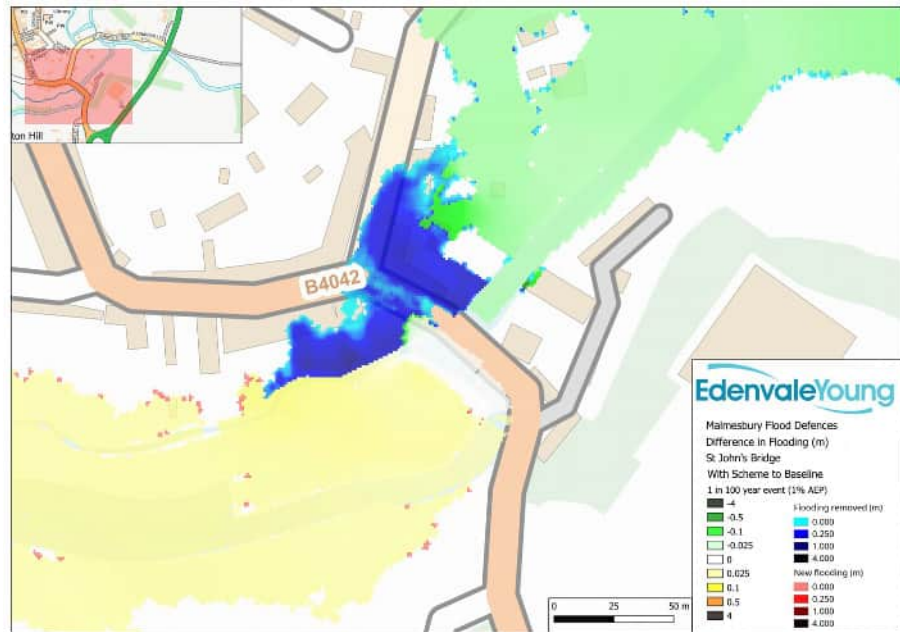


Figure 7.5: Peak Level Difference Map for 1 in 54 year return period flood event local to St. John's Bridge

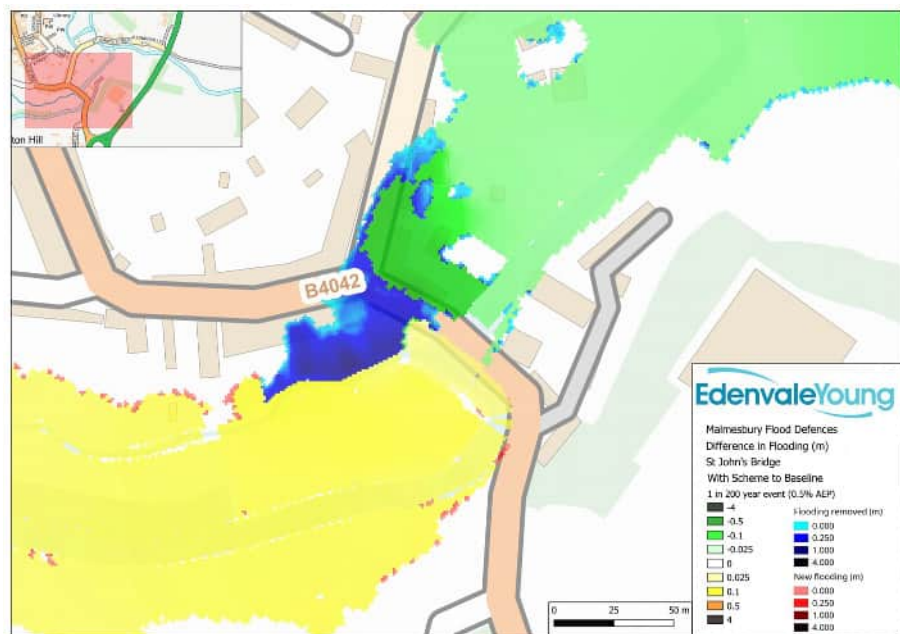


Figure 7.6: Peak Level Difference Map for 1 in 70 year return period flood event local to St. John's Bridge

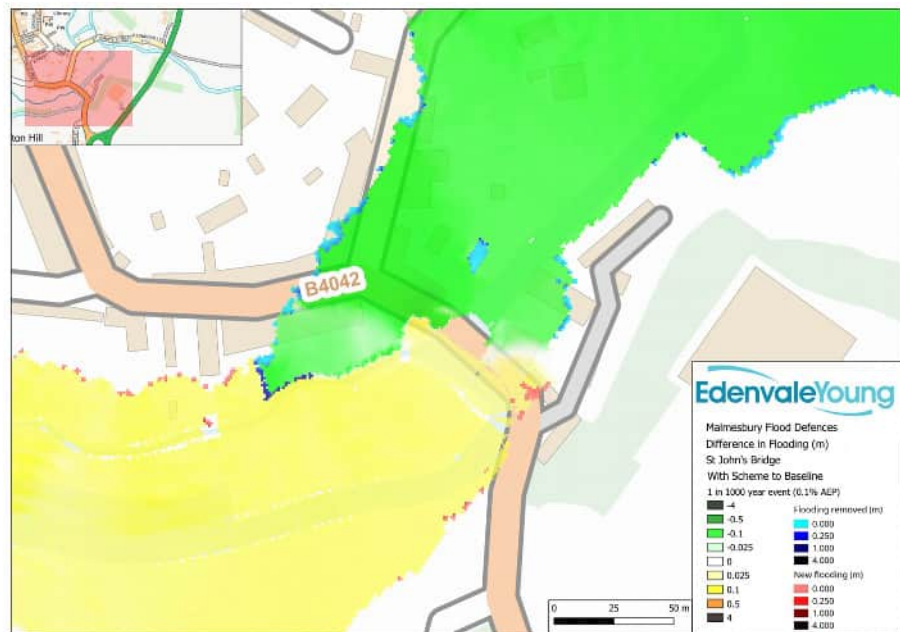


Figure 7.7: Peak Level Difference Map for 1 in 143 year return period flood event local to St. John's Bridge

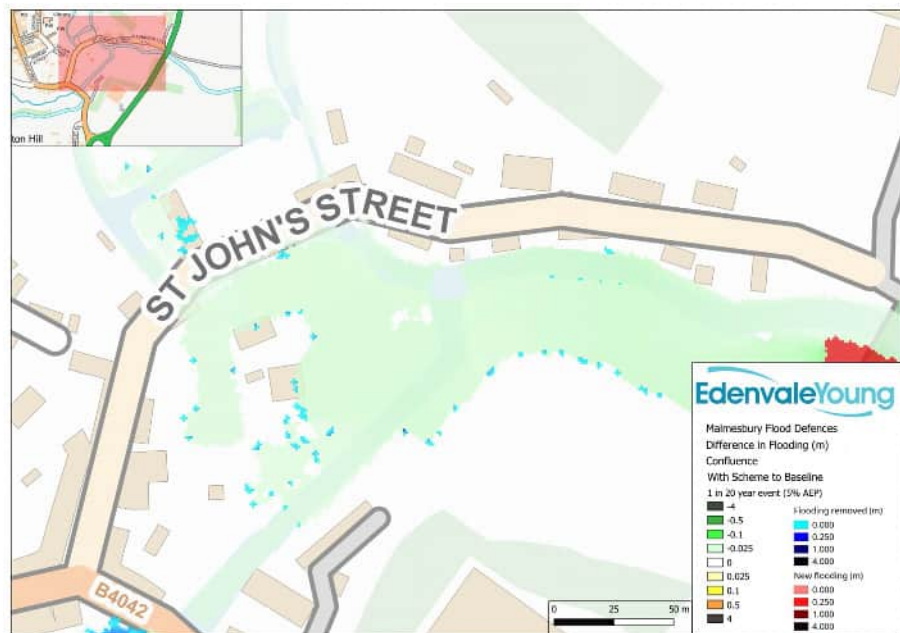


Figure 7.8: Peak Level Difference Map for 1 in 27 year return period flood event local to the Sherston/Tetbury Avon confluence



Figure 7.9: Peak Level Difference Map for 1 in 41 year return period flood event local to the Sherston/Tetbury Avon confluence



Figure 7.10: Peak Level Difference Map for 1 in 54 year return period flood event local to the Sherston/Tetbury Avon confluence



Figure 7.11: Peak Level Difference Map for 1 in 70 year return period flood event local to the Sherston/Tetbury Avon confluence

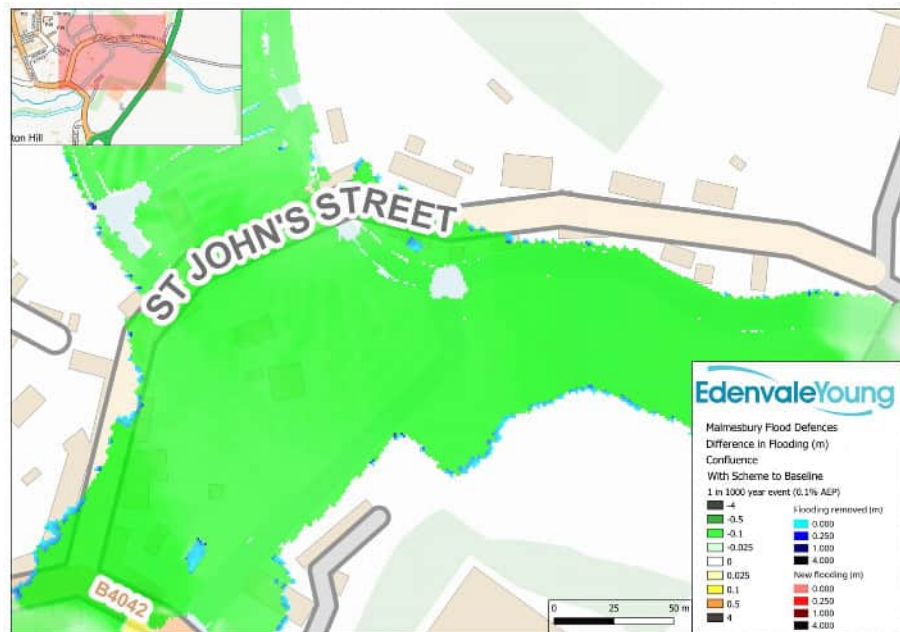


Figure 7.12: Peak Level Difference Map for 1 in 143 year return period flood event local to the Sherston/Tetbury Avon confluence

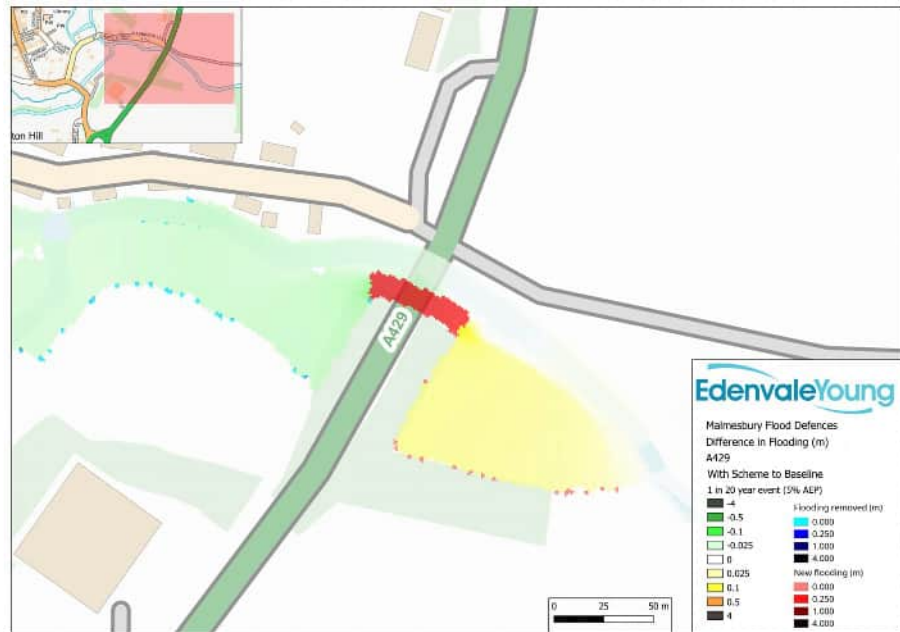


Figure 7.13: Peak Level Difference Map for 1 in 27 year return period flood event local to the A429 road bridge



Figure 7.14: Peak Level Difference Map for 1 in 41 year return period flood event local to the A429 road bridge

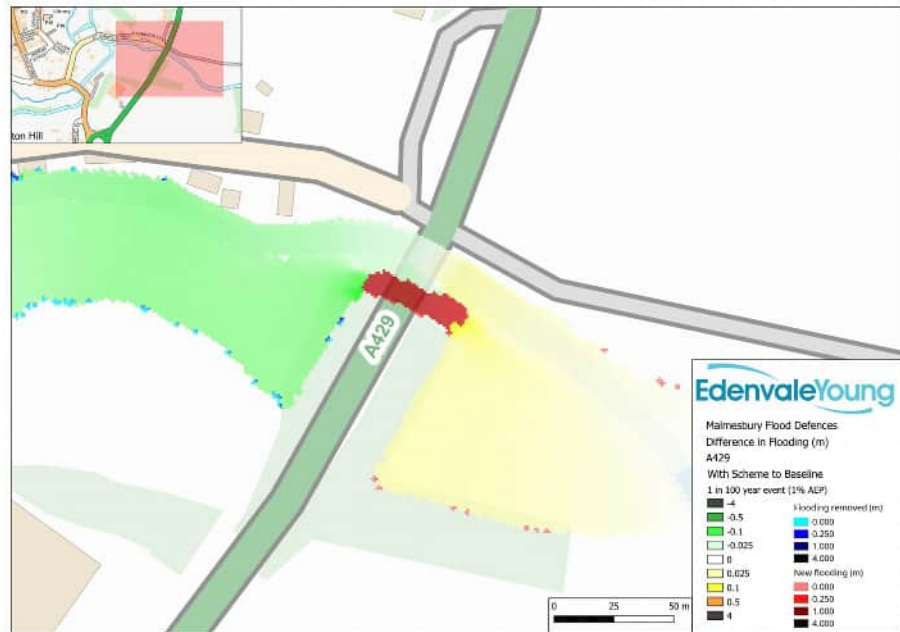


Figure 7.15: Peak Level Difference Map for 1 in 54 year return period flood event local to the A429 road bridge

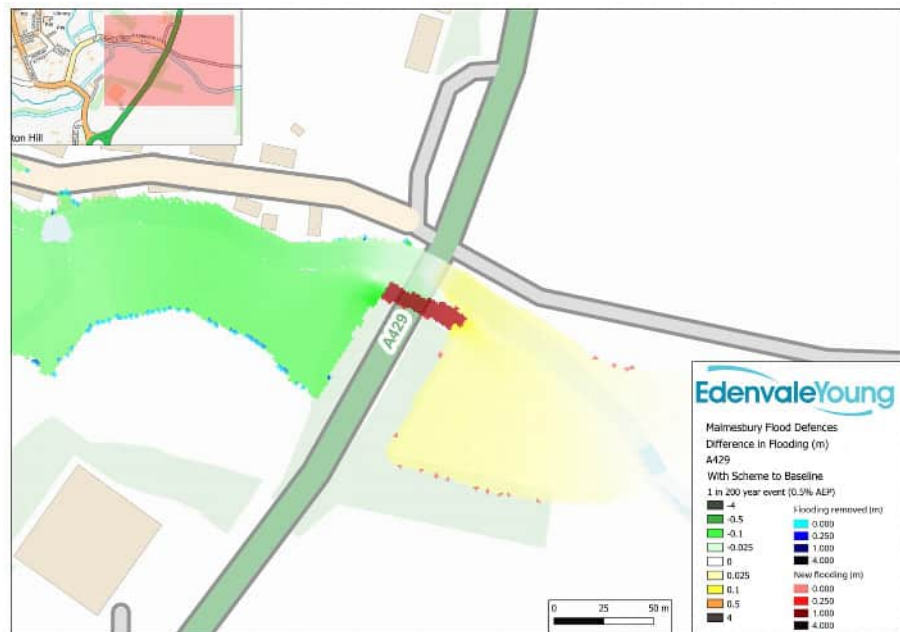


Figure 7.16: Peak Level Difference Map for 1 in 70 year return period flood event local to the A429 road bridge

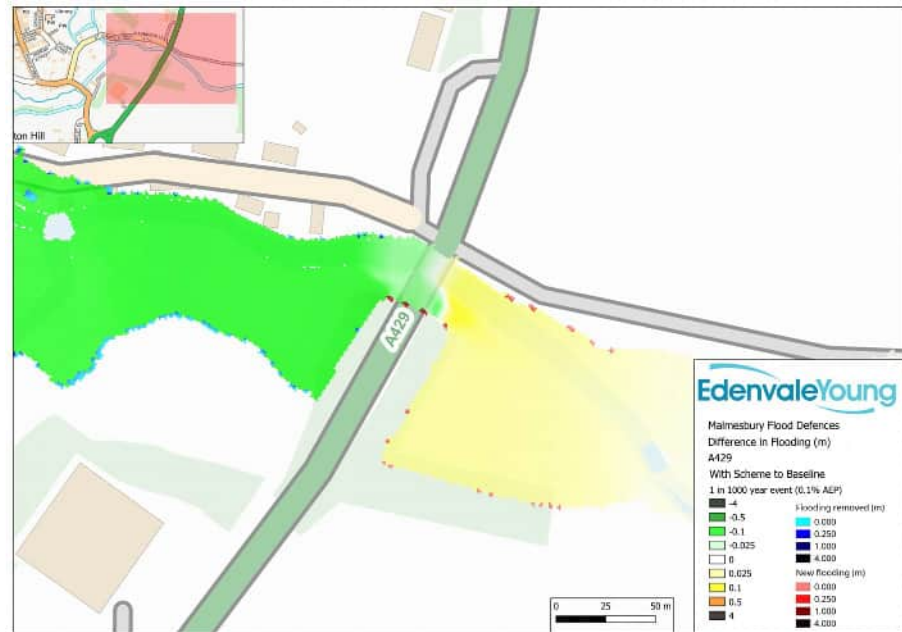


Figure 7.17: Peak Level Difference Map for 1 in 143 year return period flood event local to the A429 road bridge

## 8 Construction cost estimates for proposed scheme

The cost estimate has been produced using the SPONS Civil Engineering and Highways Works 2019 Pricebook and Civil Engineering Standard Method of Measurement 4 (CESSM4).

A summary of the costed items is shown below in Table 9.1 and the full costs are shown in Appendix A.

**Table 8.1: Summary of construction costs**

ITEM A – Reinforced masonry wall, RC apron and pumping sumps		£142,064
ITEM B – Return wall		£36,208
ITEM C – Demountable flood gates		£13,644
ITEM D – Conveyance improvement works around footbridge		£3,780
ITEM E – Lowering car park off St Johns St		£17,719
ITEM F – Flood relief channel		£1,937
ITEM G – Channel improvements beneath A429		£12,827
<b>Total</b>		<b>£228,178</b>
Preliminary costs	£10K	£10,000
Contingency	20%	£47,636
<b>GRAND TOTAL</b>		<b>£285,813</b>

## 9 Cost Benefit Analysis

The annual average flood damages were calculated by the utility in Flood Modeller using the version of the National Receptor Database dated 2014. The figures below are shown to the nearest whole pound and the return periods from the single site analysis have been employed.

Scenario	Resi	Non Resi	Vehicle	Indirect	Emergency services	Total (£)
Do Minimum	26636	33630	1369	1009	3375	66019
Do Nothing	63794	51976	4978	1559	6483	128790
Do Something	22771	31940	1105	958	3064	59838

Owing to the uncertainty associated with the flood frequency analysis and the need to represent the impact of climate change through the design life of the proposed works, it was decided to present figures assuming the return period flows occurred at twice the frequency calculated by the single site analysis which would render the November 2012 event a 1 in 27 year flood event.

*Table 9.1: Average Annual Damages for adopted scenarios*

Average Annual Damages	Assuming Single Site Analysis Probabilities (1 in 54 years for November 2012) (£)	Assuming Lowest Possible November 2012 Return Period (1 in 27 Years) (£)

Scenario		
Do Nothing	128,790	257,580
Do Minimum	66,019	132,038
Do Something	59,838	119,676

The benefits were calculated as shown in Table 9.2;

*Table 9.2: Annual Average Benefits for adopted scenarios*

Annual Average Benefit (AAB):	Assuming Single Site Analysis Probabilities (1 in 54 years for November 2012)	Assuming Lowest Possible November 2012 Return Period (1 in 27 Years)
Change in scenario		
“Do Something” instead of “Do Nothing”	£68,952	£137,903
“Do Something” instead of “Do Minimum”	£6,181	£12,361
“Do Something” instead of “Do Minimum”	£62,771	£125,542
Net Present Value (NPV) of benefits over 100 years		
Change in scenario		
“Do Something” instead of “Do Nothing”	£2,061,653	£4,123,306
“Do Something” instead of “Do Minimum”	£184,804	£369,609
“Do Minimum” instead of “Do Nothing”	£1,876,849	£3,753,697

The above table leads to the calculation of benefit/cost ratios as shown below.

The costs used in Table 9.3 below to go from a “Do Nothing” to a “Do Something” scenario also includes a 100 year discounted cost of £26,910 to cover whole life maintenance works for the proposed scheme.

*Table 9.3: Benefit cost ratios for adopted scenarios*

Change in Scenario	Assuming Single Site Analysis Probabilities (1 in 54 years for November 2012)	Assuming Lowest Possible November 2012 Return Period (1 in 27 Years)
	Ratio	Ratio
“Do Something” instead of “Do Nothing”	6.6	13.2
“Do Something” instead of “Do Minimum”	0.6	1.3
“Do Minimum” instead of “Do Nothing”	69.7	139.5

## 10 Conclusions

An improved flood model has been developed covering the central area of Malmesbury that experienced flooding during November 2012 and other more recent events.

This model generates different, generally lower, peak flood levels than the JacksonHyder model developed for the Environment Agency in 2017 for the same return period design flood events.

These results were used to estimate a return period of 1 in 100 years using the peak level recorded at the St. John’s weir gauging station in November 2012.

This return period was thought to be unrealistically high given the flood records for the town and a single site hydrological

analysis was undertaken to generate a further estimate of return period for this event. This required development of a new rating relationship at St. John's weir using the updated model and it was shown that this relationship was consistent with historical spot flow gaugings at this gauging station.

The single site analysis showed that the return period for the November 2012 event was reduced to 1 in 54 years which was still thought to be too high. A pragmatic estimate of the current and medium term future return period was between 1 in 25 years and 1 in 40 years given that climate change will generally reduce return periods over time.

The proposed community led scheme was implemented into the updated model as well as a "do nothing" scenario which involved introducing blockage at both St. John's Bridge and the A429 road bridge.

Modelling showed that the proposed scheme removed 20 properties from the flood extent for the November 2012 event and generated reductions in flood risk throughout Malmesbury for return period floods between 1 in 20 years and 1 in 1000 years.

The proposed scheme was also costed using the SPONS Civil Engineering and Highways Works 2019 Pricebook and Civil Engineering Standard Method of Measurement 4 (CESSM4) and a cost of just below £286,000.

According to cost benefit analysis this showed a benefit cost ratio between 6.6 and 13.2 depending on the return period adopted for the November 2012 flood event. The lower figure assumes the 54 year return period and the higher figure assumes a 27 year return period for this event.

## **11 Recommendations**

The analysis presented herein has shown that a healthy benefit cost ratio has been generated for the proposed community lead scheme and it is recommended that further work is undertaken to prepare detailed designs and construction drawings.

It is further recommended that the updated model is used to inform an improved flood warning service for the town of Malmesbury as well as improved flood mapping for the town.