# Mold Flood Alleviation Scheme

# Smart Flood Management

## Feasibility Study and Opportunity Map

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## DOCUMENT REVIEW & APPROVAL

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## Introduction

Mold has a long history of flooding with extensive residential and commercial areas having suffered in the last decade on several occasions. Previous studies have identified some 81 residential and 10 commercial properties as being at risk of flooding. One of the areas, Cae Bracty, is particularly prone to flooding. An earlier flood alleviation scheme encountered budget constraints and landowner objections.

Waterco were commissioned by Flintshire County Council (FCC) to look at the use of Smart Flood Management (Smart FM) to reduce flood risk more cost effectively. Smart FM is an extension of Natural Flood Management (as further described in the next section).

This feasibility study aims to build upon the previous investigations by exploring ways in which Smart FM can reduce flood risk in Mold from fluvial flows generated in the upper catchments, as well as the pluvial flows generated by the rainfall directly over the town; and in particular, the following:

1. **Infrastructure improvements:** using the existing pipework model (developed as part of the FAS study) to examine whether relatively short lengths of upsized or dual culvert would make a worthwhile difference to the overall system capacity.

2. **Upstream catchment attenuation using Smart FM:** investigate opportunities for 'smart' natural flood management - such that relatively small storage volumes, activated just at the peak of the event, will allow the infrastructure (improved as item 1) to carry residual flows.

3. **Cae Bracty:** undertake a study of this area and in conjunction with the development of infrastructure and attenuation options (in the context of items 1 and 2 above); consider the available options.

4. **Catchment diversions:** assess the potential for retaining part of the proposed cut-off drain (present FAS) and also consider a directional drill tunnel to take some flow directly to the River Alyn.

Flintshire CC also asked that the study take account of the following:

1. **Constructability**: Cost effective solutions, that can be delivered efficiently through collaboration with contractor, consultant and client

2. **Effectiveness**: demonstrating the benefits to be realised from a pragmatic, staged approach

3. **Affordability**: budget costings need to be realistic to avoid 'ballooning' costs during the detailed design stage

4. **Reliability**: ensuring any new approach has no risk of failure.

## Smart Flood Management Approach

The principle objectives of Smart Flood Management can be expressed, in simple terms, as follows:

1 optimise the flood flow capacity of the existing system

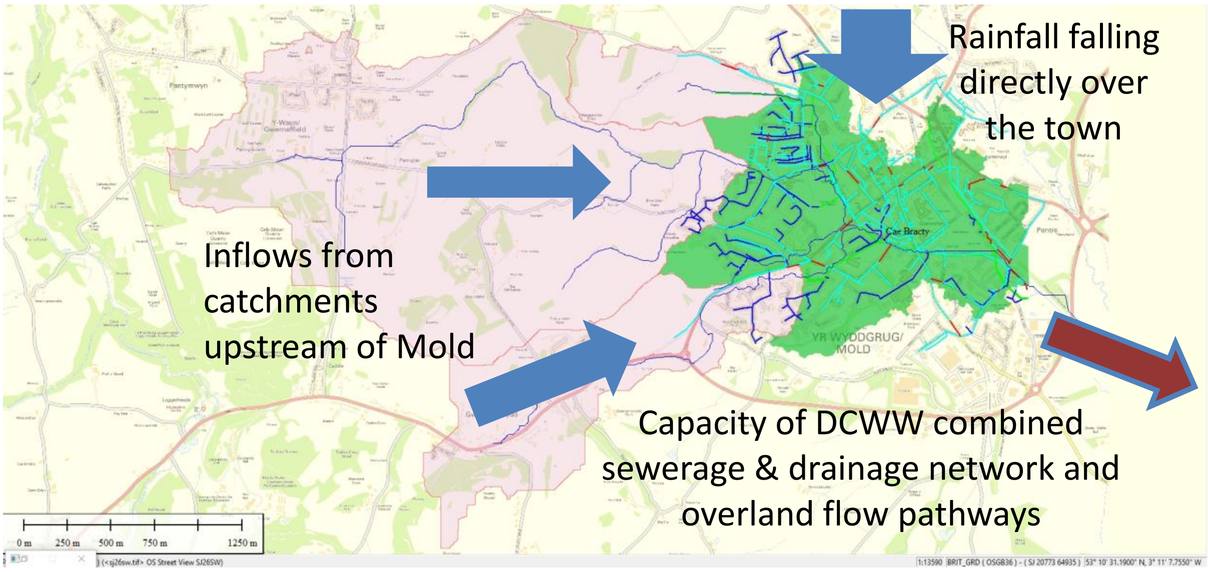



Figure 1: Integrated model for Mold Smart Flood Management System

2 attenuate, through attenuation storages, the peak flows

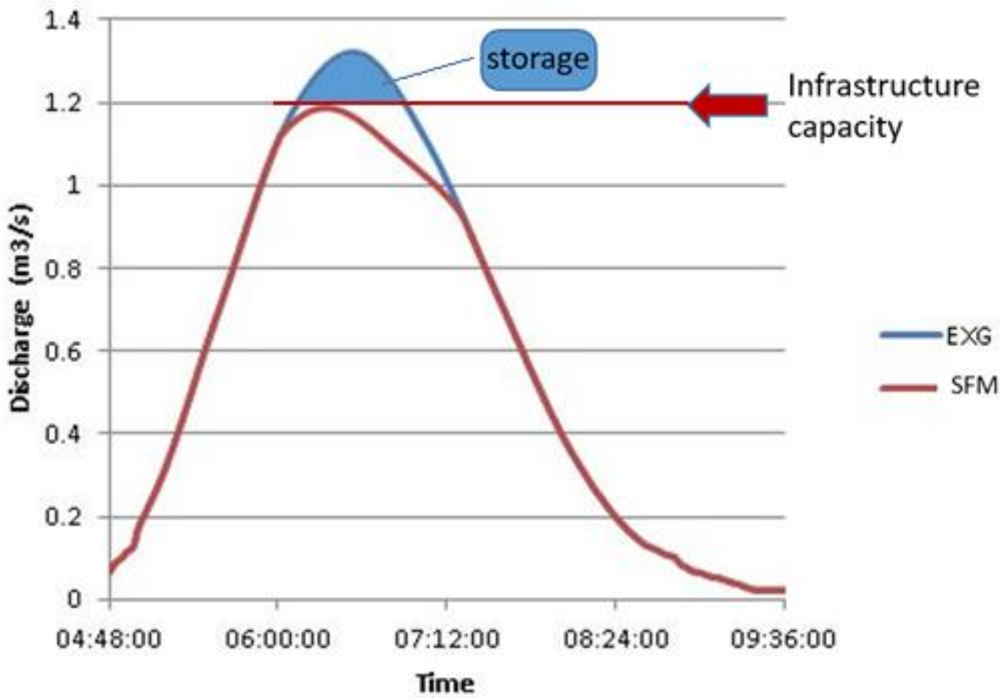



Figure 2: Assessing attenuation storage capacity for a Smart Flood Management system

In Natural Flood Management, each sub-catchment that has either an ephemeral or permanent channel can be enhanced with storage and attenuation features for 'slowing the flow'. Smart FM also utilises the principle of 'slowing the flow' by creating attenuation storage capacity which complements and enhances the capacity of the existing system.

Smart FM comprises:

i) assessing the 'optimised capacity' of the waterway for flood prevention,
ii) assessing peak flood flows derived from hydrological analysis,
iii) assessing attenuation storage(s) in various parts of a catchment,
iv) actively managing the attenuation storage(s) using control structure(s) to ensure the peak flow rate through the waterway does not exceed its 'optimised capacity'.

The components of a Smart FM system, optimised to work at the right time for the duration of a flood event, results in the management of exceedance flows which, ordinarily, would exceed the system capacity, thus preventing flooding with a significant increase in cost-effectiveness, compared to NFM and traditional flood defence systems.

Attenuation storages provided closer to the at-risk area work more efficiently compared to distant attenuation storage sites, i.e. those in the far reaches of the catchment will generally be less cost effective and may require a careful evaluation of the relative benefits of passive versus active smart control.

The potential for implementing Smart FM for alleviating flood risk to Mold is to be undertaken in conjunction with examining whether relatively short lengths of upsized or dual culvert would make a worthwhile difference to the overall sewerage & drainage system capacity.

## Hydrology

The hydrology is primarily concerned with the rural catchments where storage and control have the space and timescale to operate within Smart FM. FEH data indicates two main catchments, the larger containing Gwernaffield and the smaller containing Gwernymynydd, please see Figure 3. A much smaller catchment incorrectly assigned by FEH data to the River Alyn is seen as a rectangular section by NW Mold, it is designated later as catchment 'I' or Fir Grove.

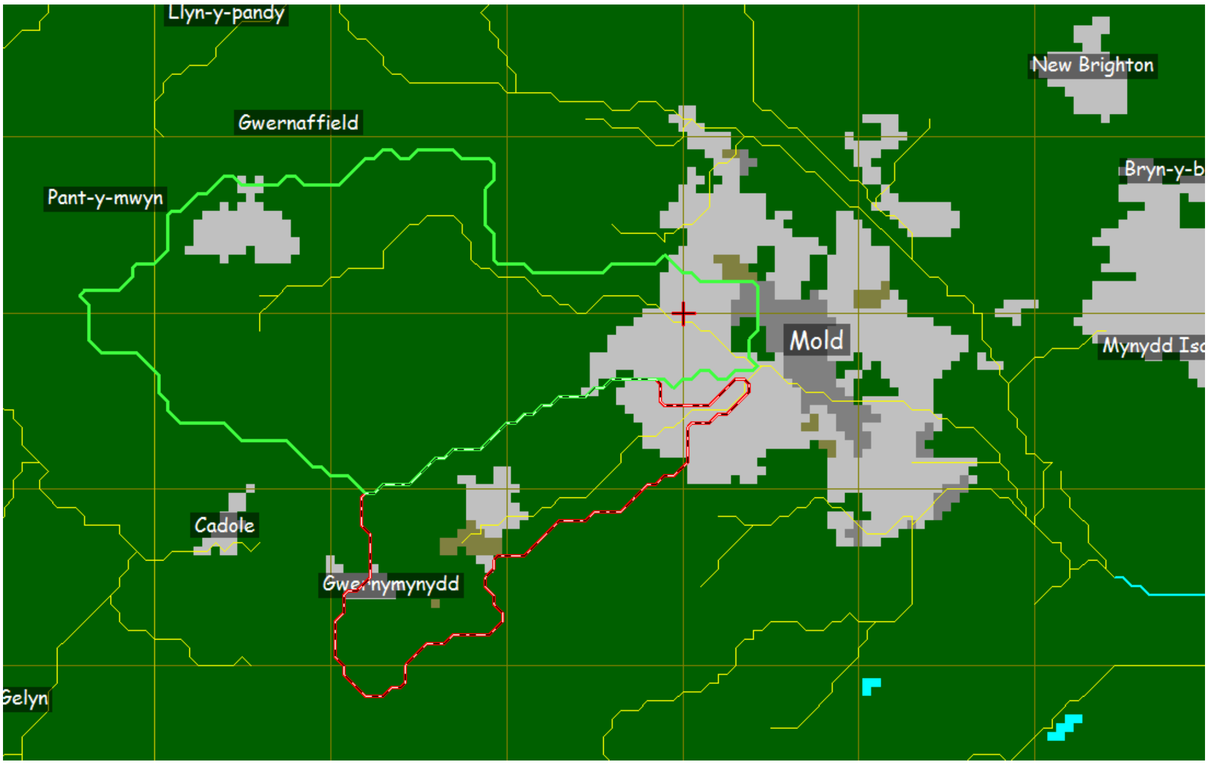



Figure 3 Main catchments: Gwernaffield (green outline) and Gwernymynydd (red outline)

The two main catchments are somewhat different in respect to flows from modelled rainfall events. ReFH software indicates that the Q100 flow of the smaller catchment Gwernymynydd is much larger per unit area than the larger Gwernaffield catchment. Table 1 shows the ReFH catchment flows at the confluence of the two natural catchment streams in Mold, and the ReFH flows to Brook St and two potential storage areas.

Table 1: Catchments draining into Mold

| Catchment | Area ($km^2$) | BFIHOST | Q100 ($m^3/s$) | Q100 per unit area (l/s/ha) |
|---|---|---|---|---|
| Gwernaffield (to confluence in Mold) | 4.15 | 0.71 | 2.2 | 5.3 |
| Gwernymynydd (to confluence in Mold) | 1.71 | 0.59 | 1.8 | 10.5 |
| Gwernaffield+Gwernymynydd at Brook St. | 6.07 | | 3.8 | |
| Gwernaffield at Marsh storage | 3.21 | | 1.8 | |
| Gwernymynydd at Ruthin Road storage | 0.92 | | 1.6 | |
| Fir Grove (catchment 'I') Rural | 0.6 | 0.85 | 0.2 | 3.3 |

OS mapping from 1888 indicates the route of the Gwernaffield catchment stream to have been on the edge of urban Mold at that time. It flowed in an open channel towards the cricket ground and was diverted around the cricket field, across the Ruthin Road/New Road, to alongside the area currently known as Cae Bracty, finally on to Brook street and Gas Lane. The culverted route is very similar to the original open channel route and during more extreme rainfalls the overland route will follow the culverted route; albeit that raised road surfacings will mean considerable ponding.

Gwernymynydd catchment stream is shown in 1888 OS mapping to be open channel alongside the Ruthin Road until Hendy Road. It now appears to have been diverted into a smaller catchment stream to the south causing overland flows and piped flows to flow along parallel paths as the flows approach Cae Bracty.

The design storm approach using ReFH relies heavily on the soil loss model. The model assumes the catchments are initially fairly dry (Gwernaffield) and fairly wet (Gwernymynydd). Should the antecedent wetness be much higher than expected from a series of closely spaced smaller storms followed by the design storm, the Gwernaffield catchment, in particular, will have markedly increased volumes for Q100 flows. The FEH statistical method used in the previous study by CES Ltd gave higher values than ReFH, but the choice of good close donor stations is limited.

The Gwernaffield catchment is affected by mining drainage. The Milwr tunnel was driven below the northern boundary of the catchment in 1948 (estimated) and passed out of the catchment by 1955 (estimated) to terminate at Cat Hole (now called Cadole) in 1957. The drainage tunnel intersects several other east-west mineral vein mining tunnels. The effect is a reduction in the antecedent wetness of the east portion of the catchment. This would dry the soils beyond what the ReFH model estimated and may reduce peak flows. However, more extreme events that can raise the saturation levels of the shallow soils quickly have a timescale which would be too rapid for the mining drainage to effectively reduce peak flows.

The smaller Gwernaffield flow per unit area is partly explained by the soils of the catchment: having a large area on limestone, where soils are thin and the drainage rapid into the limestone below, i.e. a higher BFIHOST. In contrast, Gwernymynydd has a proportionately larger area of deeper soils over less porous glacial till. It is also about 20% steeper according to the DPSBAR catchment descriptor and has more urbanisation per unit area. These combined effects make Gwernymynydd a flashier catchment than Gwernaffield.

Volumes from Q100 design storms are approximately 48,500 $m^3$ (58,300 $m^3$ with climate change allowance) and 87,200 $m^3$ (104,700 $m^3$ with climate change allowance) from Gwernymynydd and Gwernaffield catchments, respectively.

Total Q100 flows entering Mold in the Cae Bracty catchment are uncertain due to smaller catchment routes and urban diversions both through culverts and overland. A suitable estimate is found by adding Table 1 values for the combined Gwernaffield / Gwernymynydd catchments with Fir Grove (rural plus urban) and the uncertain Gwernymynydd B catchment. The Q100 value for the combined catchments without critical storm duration analysis is 3.8 $m^3/s$ at upper Brook St.

### Identification of subcatchments

Watershed software, GlobalMapper was used to compare smaller subcatchments with OS mapping. Generally OS mapping defines and maps permanent streams whereas GlobalMapper defines flow routes based on the underlying topography, a combination of LiDAR and OS 50 data in this case. If too fine a subdivision of catchments is carried out, the results can be physically meaningless as channels are not present. The presence of an ephemeral but dry channel is an important indicator of long return period flows, dependent on soil and rock types.  Figure 4 shows the GlobalMapper generated streams and subcatchments using a 0.1km$^2$ stream catchment generation area.

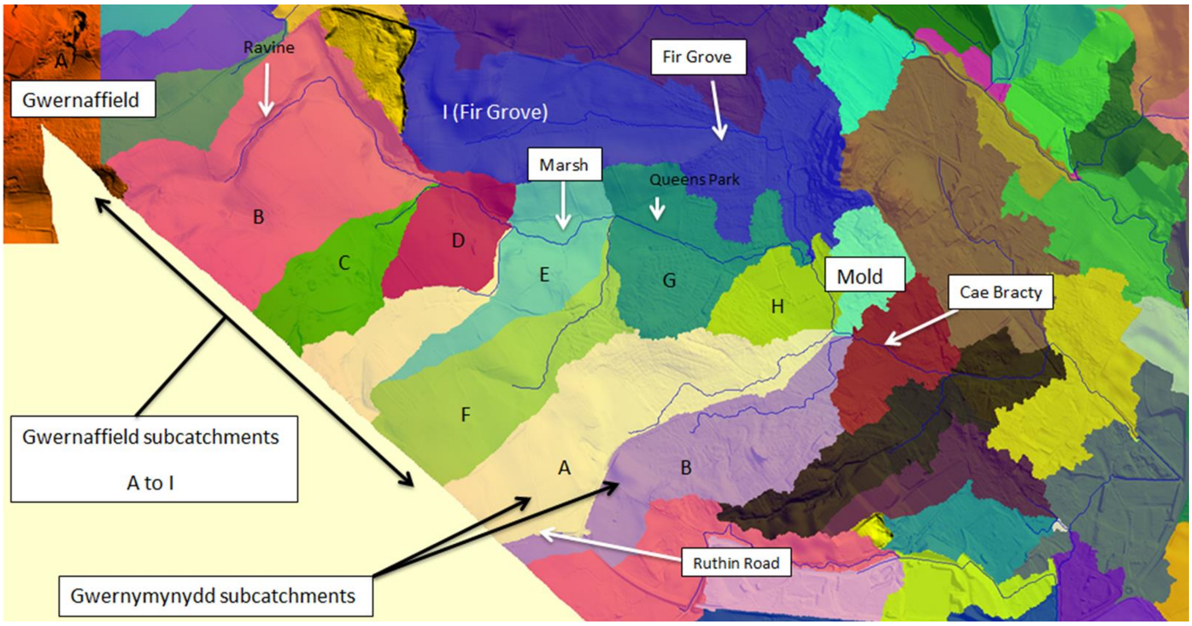



Figure 4: GlobalMapper generated catchments

### *Gwernaffield catchments*

Travelling upstream, the stream from the confluence in central Mold passes through Mold urbanised subcatchments H and G before exiting at Queens Park where it has been channelled in a straight line through the field. It is shown by OS mapping to stop well before the ravine and it presumably becomes ephemeral. Its dry channel is clear from LiDAR and geological maps as it extends to just south of Gwernaffield. The 10m deep ravine in catchment B (Figure 4) is likely to be a paleochannel but it is also an indication that the flow network for extreme events has the ability to generate large flows rapidly. Earlier OS mappings show this ravine stream to be permanent but land use changes and/or water abstraction may have altered flows.

The catchment beyond the ravine (NGR 321535 364558) has an area of 1.6km$^2$ that can, according to ReFH, generate a Q100 flow of 1.1 m$^3$/s and a Q100 volume of about 10,000 m$^3$, making the ravine an area of interest for attenuation storage.

Streams generated as drainage routes in catchments C, E and F are present in OS mapping but appear to be culverted or piped in parts of their routes. Flows from catchments C, D and the unlettered catchment south of D could be captured in the marsh area (NGR 322456 364032). This area is currently felled woodland and is biologically degraded. It is an excellent location for bunded storage and could be revitalised as an ecologically valuable bog. Close by on the edge of urban Mold by Queens Park is a field through which the main stream flows from 90% of the catchment area. It too has an excellent bunded storage potential.

Catchment 'I' or Fir Grove, about 0.6 $km^2$ rural and another 0.25 $km^2$ in urban Mold, see Figure 4, enters Mold through Fir Grove and passes into a low spot flowing south past the Mold Community Hospital. The catchment has a high BFIHOST and from its small area is unable to generate a permanent stream channel. The hospital channel has probably been deepened and is mapped as permanent. Unfortunately, the ephemeral stream route was urbanised many years ago by Fir Grove. This area behind Fir Grove housing in the field is an area of saturation excess overland flow where flows converge during wet periods and emerge from the ground. They may appear as an overland flow flash flood but most of the flow is probably from below ground. At some stage a pipe was laid for some distance under the shallow valley floor of the catchment. This now carries flows direct to the Mold Community Hospital channel and on in to central Mold. Ditching alongside Maes Garmon Lane may be connected to this artificial route. Overall, the pipe and ditching have added a significant Q100 flow to central Mold where once the flow would have been minimal and slow to react. Note that catchment 'I' is designated as Gwernaffield (Catchment B) in previous reports by CES Ltd.

Q100 flows from catchment 'I' in total (rural and urban) are suggested by ReFH scaling to be about 0.4 $m^3/s$. Interception of this flow would require more effort than the other catchments. It can be achieved by using a simple bund, or as suggested in a previous FCA by CES Ltd using a cutoff culvert, however flows could be bypassed underneath by saturated groundwater. This may leave about 0.2$m^3/s$, during Q100 flows, entering Mold north of Cae Bracty.

### *Gwernymynydd catchments*

Gwernymynydd's subcatchment 'A', Figure 4 is the main catchment. It is piped in urban Gwernymynydd and reappears following the A494 until culverted again just before the A494 bypass roundabout along a cut-off section of road. It reappears in open channel along the Ruthin road and becomes culverted again entering urban Mold. The stream channel is very variable in width having been trained in places but also constrained by materials dumped into the stream channel.

Gwernymynydd's subcatchment 'B' is mainly an urban catchment. OS 1888 mapping shows it to be ditched and directly connected to the channel at Cae Bracty. However, it is now culverted except south of Highfield Villas and at some stage Gwernymynydd's catchment 'A' pipe was diverted into it from near Hendy Road. The upper drainage route may have been altered by the Mold bypass route. Its estimated area is 0.43 $km^2$ though its contribution to flow requires more investigation and a preliminary estimate of Q100 flow is about 0.3$m^3/s$. This flow is not included in Table 1 flows due to the uncertainty of catchment routing.

### *Cae Bracty urban subcatchment*

Cae Bracty of about 2500$m^2$ in area to the 108.5m contour using 2m resolution LiDAR is located in a small depression embedded in a larger catchment of about 0.15 $km^2$ in area, see Figure 5, which originally, seen on 1888 OS Maps, drained directly into the ditched open channel stream. This larger catchment, here designated Cae Bracty, will in storm conditions overwhelm local drainage and attempt to re-engage with the original drainage route along the line of the culvert above it, but subject to deviation by subsequent urbanisation. The Cae Bracty catchment falls towards the culvert line more steeply from the SW, mean gradient 0.033, than from the NE, mean gradient 0.014. Only part of the larger Cae Bracty catchment, perhaps 20%, flows towards the Cae Bracty depression in storm conditions. However this area, along with the culvert flowing at full capacity, is more than sufficient to flood Cae Bracty in storm conditions.

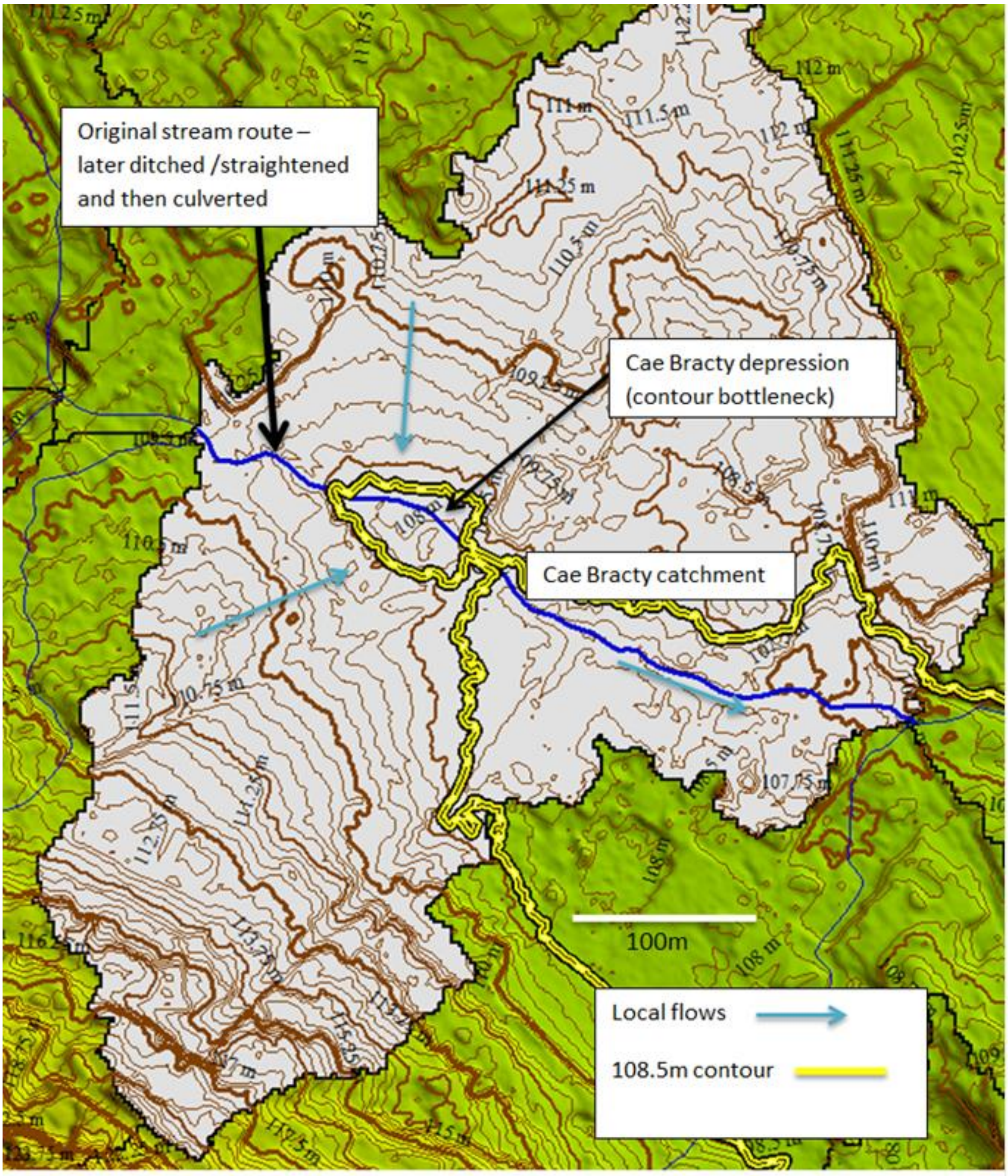



Figure 5: Cae Bracty catchment

## Infrastructure improvements

The residential and commercial properties in Mold are at risk of flooding from the inflows from the upstream catchments as well as the rainfall falling directly over the town. The drainage network in Mold consists of streams entering the town from upper catchments passing into culverts and being joined by surface water drainage and also a (legally) separate Dwr Cymru Welsh Water (DCWW) combined sewerage & drainage network. The previous study mentions of modelling some 15km of surface water drainage network and 28km of combined sewerage & drainage system.

The previous modelling exercise updated and constructed a detailed 1D/2D model of River Alyn and the preferred alignment of the proposed cut-off channel. Some modelling of the flooding mechanism in the town was undertaken.

The previous modelling exercise did not appear to consider the effect of possible sewerage & drainage flow contributions from elsewhere such as Gwernymynydd and possibly Buckley. Although that exercise evaluated options of adding storage to the sewerage & drainage system as well as creating a wetland, it did not evaluate any upgrades to the sewerage & drainage system that has developed independently over time, such as the removal of adversely sloped pipes and bottlenecks in the system. Sewerage & drainage improvements can augment the capacity of the system and any improvement to the capacity of the sewerage & drainage system should result in a reduction in the quantity of required offline or online storage. Further, the systems were modelled in isolation. The previous flood models are a mixture of MicroDrainage (pipes, channels but seems to be used mainly for hydrology) ESTRY (fluvial, urban drainage), ISIS (fluvial) and TUFLOW (urban surface) models.

The available modelling data provided by FCC shows some network data, see Figure 6.

Figure 6: Missing information and network issues

Of the above, the first dataset could only be used for the network modelling due to missing information in the other datasets. Additionally, no information on the pumping station at Cae Bracty could be found. Depending on the level of confidence and detail required at any subsequent detailed design stage, such information may be useful or indeed necessary.

This dataset has been used together with the LiDAR data in this study to build, using MIKE Urban software by DHI, a single integrated model comprising a 2D surface water flood model that is linked to both the 1D surface water network with catchment flows as boundary conditions and the 1D sewerage & drainage network, see Figure 7. The rainfall has been applied directly on to the 2D surface model. The MIKE Urban software has the capability to model catchment flows in 2D, connect the flows to either the 1D river network or both the 1D river network and the 1D sewerage & drainage network. Flows enter from a 2D surface to the 1D networks by draining from the 2D surface, or conversely spill onto the 2D surface from the 1D network and generate flooding. This enables alterations in one part of the system to directly interact with the other elements, giving a better picture of the overall system. Thus, it provides a better configuration representing the flood mechanism.

The newly built model for Mold is substantially different to the previous model which focused on the cut-off channel and the River Alyn. The new model effectively models the potential interventions in the catchment as well as in the urban areas.

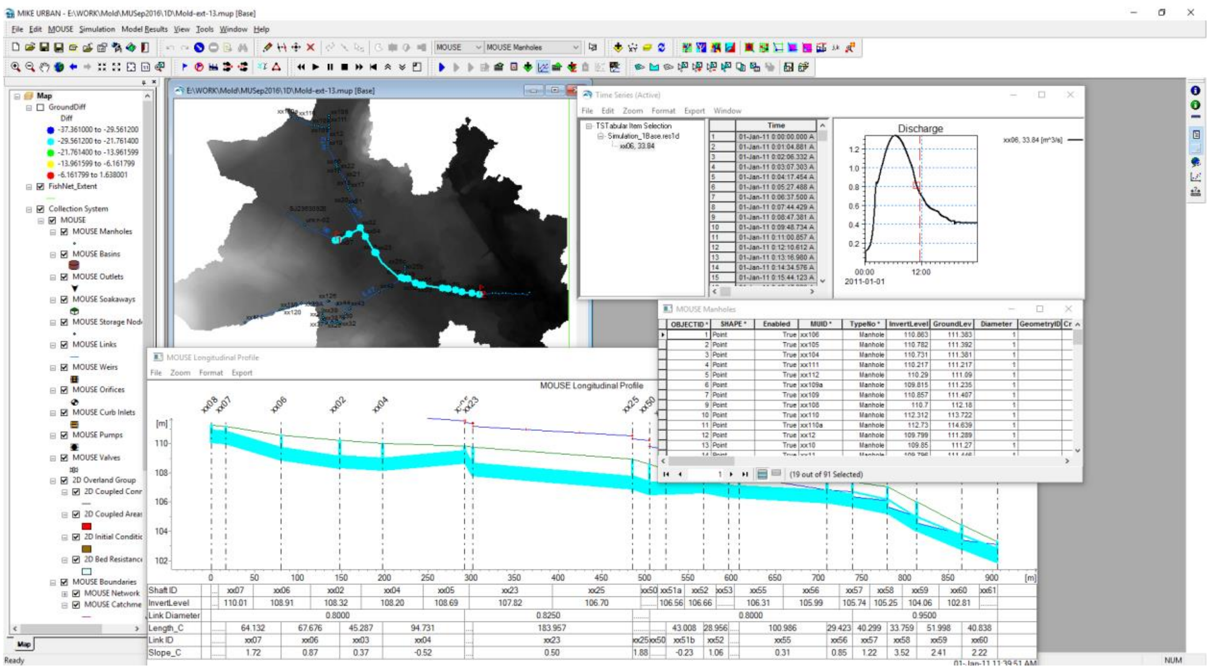



**Figure 7: MIKE Urban model setup**

The existing urban drainage was investigated to explore potential improvements that could be made to convey significantly more flows; such as removing bottlenecks and adding capacity over short stretches of the network. Investigations identified some restrictions and bottlenecks in the system near Cae Bracty. The works to remove these restrictions and bottlenecks would be limited to the sections where additional capacity can be achieved without a need to disturb most of the network as shown in Figure 8.

By removing some restrictions and bottlenecks and allowing some overland flow to occur in the integrated model, see Figure 9, it is estimated that a throughput of some 1.4 cumecs could be achievable from Cae Bracty onwards.

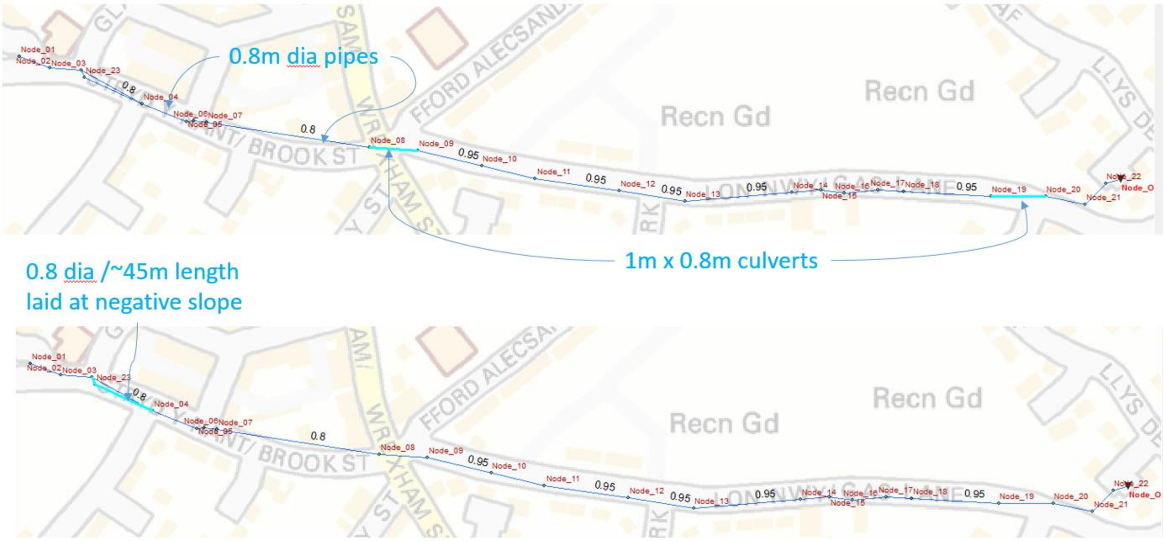



Figure 8: Potential locations for infrastructure improvements

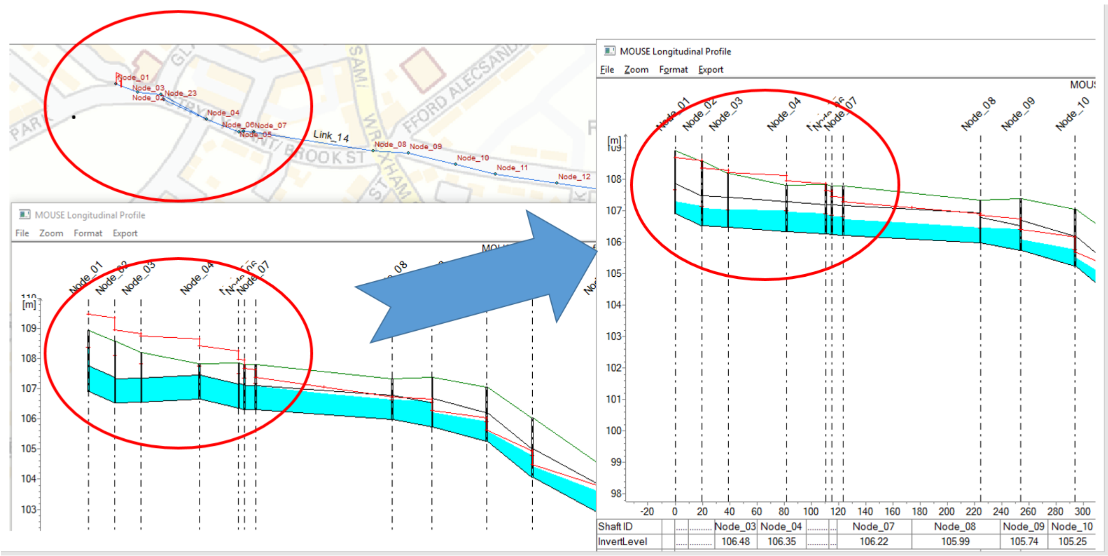



Figure 9: Model output showing reduction in max flood depth post network improvements

More bottlenecks were also noticed in parts of the town upstream of Cae Bracty, see Figure 10. It needs to be noted that adverse falls, although troublesome from a siltation point of view are not necessarily a bad thing for the network as they can act to hold back (attenuate) flows.

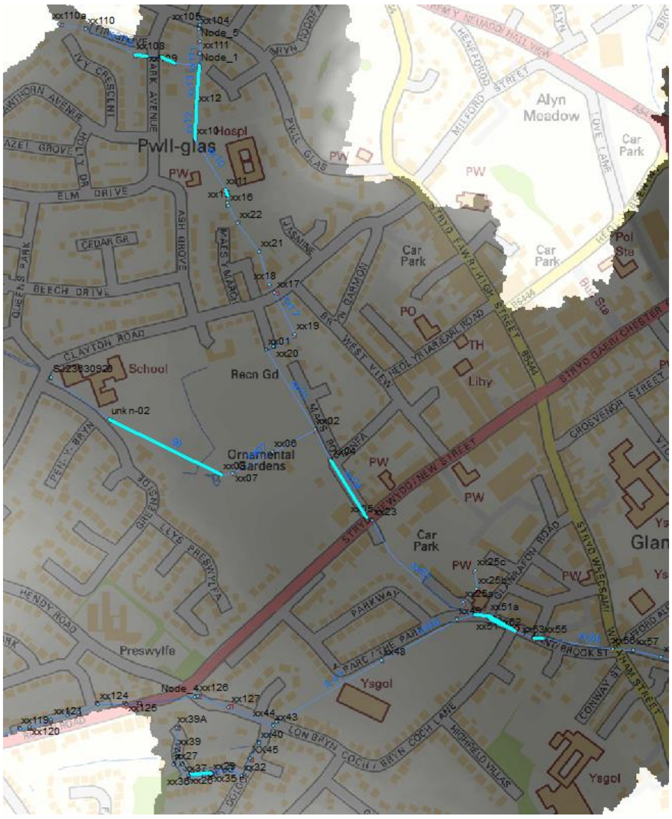



Figure 10: Negative slopes elsewhere in the sewerage & drainage network

However, it was found that removal of the restrictions and bottlenecks in the system near Cae Bracty only marginally alleviates the flooding to the properties, see Figure 11.

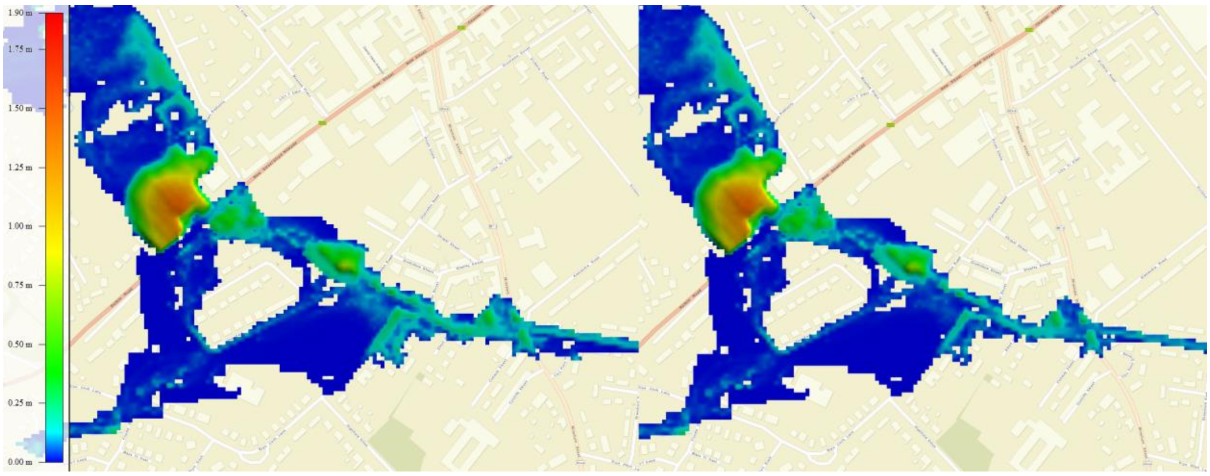



Figure 11: Max flood extents near Cae Bracty comparison for 100CC event

The limited benefit can be attributed to the topographic depression in which Cae Bracty is located. (see earlier Hydrology section). Changes to the drainage at Cae Bracty, such as a separate pipe from the lowest level at Cae Bracty or actively managing the flows using the pumping station, appear to be needed.

Further investigations were undertaken to identify locations of flooding from Gwernaffield as shown in see Figure 12, Gwernymynydd and Fir Grove catchments separately. This exercise identified that flows from all the catchments need to be managed to alleviate flooding to Mold.

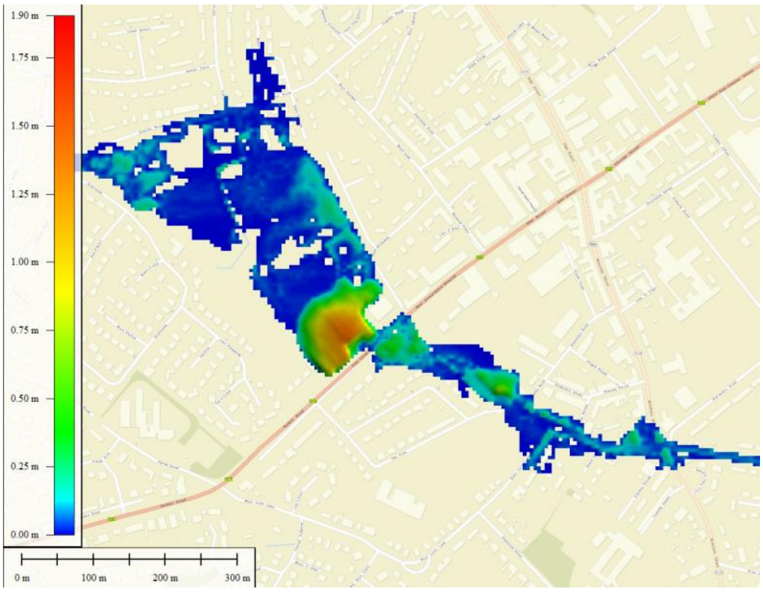



Figure 12: Max flood extents from Gwernaffield flows only for 100CC event

There is a significant drainage constraint at Cae Bracty where two 850 mm drains and one 600mm join together, but the combined outlet is still only 800 mm diameter. The cost of a new dual pipeline will be high, but the benefits to the system and to Cae Bracty in particular will be significant. The practicality of installing a new pipeline down Brook Street and crossing the Wrexham Road into Gas Lane should be investigated. Hydraulically a new 600mm should suffice, but if space permits a new 800mm should be installed so that the existing one can be refurbished and potential blockage and flow constraints due to service crossings can be investigated and rectified.

## Upstream attenuation storages for Smart FM

### Attenuation storage volumes

The flow rate which could be safely conveyed past a given location of interest provides the context for calculating the required upstream storage volume for alleviating flood risk at a specific downstream location. At Cae Bracty, it has been assumed that a flow rate of 1.4 $m^3/s$ can be safely conveyed without overland flow which can increase to 2 $m^3/s$ by allowing shallow flooding of the road. It was also noted that for the network upstream of Cae Bracty to remain flood free, further flow restrictions are required on the peak flow entering the drainage system. The required storage volumes in the catchments with these considerations have been estimated as given in Table 2 below.

Table 2: required attenuation storage volumes for individual catchments

| Catchment | 100yr+CC peak flow rate ($m^3/s$) | Peak flow rate after SFM ($m^3/s$) | Required attenuation storage volume ($m^3$) |
|---|---|---|---|
| Gwernaffield | 2.2 | 0.5 | 32,800 |
| Gwernymynydd | 1.8 | 0.5 | 18,600 |

A higher level of attenuation in one of the catchments may mean a lower level of attenuation could be provided in the other. It is immediately apparent however that these storage areas would require construction and ongoing monitoring under the Reservoirs Act. This is discussed further in later sections.

### Storage sites

Exploration of potential attenuation storage sites has been undertaken using topographic and land use data. Preference has been given to natural topographical depressions to achieve attenuation storage with minimal requirement of structures. Particular attention has been given to the existing land use to minimise potential difficulties involved in securing land. No landowner engagement has been undertaken at this stage, given the sensitivity of the Mold Flood Alleviation scheme.

One of the benefits of Smart FM is that the controls for the usage of the potential attenuation storage areas can be configured in such a way that the land is flooded for only a short period, so that the existing land use is not significantly affected. Any proposed structures, including the control structures will need to be sited in such a way as not to interfere with the existing land use activities.

Consideration should also be given, at the detailed design stage, to maximising the benefit by possible modifications to the proposed schemes to achieve additional benefits, such as biodiversity, social and environmental health and wellbeing, which may unlock additional funding for the scheme.

For the Gwernaffield catchment, the ravine in the upper catchment was initially identified as a possible suitable site. However, further identified sites, at the marsh and Queens Park field, in the lower catchment are preferred over the ravine due to their further downstream location and therefore their ability to attenuate flows from a larger portion of the catchment.

An excellent location for the Gwernymynydd catchment attenuation exists alongside the Ruthin Road Roundabout NGR 323250 364850) to catch a significant flow from the catchment, as 50% of the catchment drains through that point. Part of the land is not in productive use, is visually poor and would provide a high-profile site to demonstrate positive action is being taken in relation to flood risk reduction.

Moving down the catchment to find further attenuation storage and to intercept more of the flow is hindered by a more diffused flow path and entry into urban Mold. However, as this catchment is flashy and the single storage site only covers 50% of the total catchment area, it is considered important to investigate storage options in the urbanised Gwernymynydd 'A' catchment and in urbanised Gwernymynydd catchment 'B'.

Key information about the attenuation storage areas is presented in Table 3 and figures ( Figure 13 to Figure 15) below.

Table 3: Salient details of the identified attenuation storage areas

| | Name of the Attenuation Storage Area | | |
|---|---|---|---|
| | **Marsh** | **Queens Park** | **Ruthin Road Roundabout** |
| **Area** | 20,720 sqm | 29,360 sqm | 22,750 sqm |
| **Bund height / level** | 4m / 121.0 mAOD | 2m / 116.0 mAOD | 2m / 144.0 mAOD |
| **Bottom level** | 117.0 m | 114.0 m | 142.0 m |
| **Max water depth** | 3.5 m | 1.5 m | 1.5 m |
| **Max WL** | 120.5 mAOD | 115.5 mAOD | 143.5 mAOD |
| **Max storage volume** | 26,060 $m^3/s$ | 39,610 $m^3/s$ | 15,095 $m^3/s$ |
| **Required attenuation storage volume (from Table 2)** | | 32,800 $m^3$ | 18,600 $m^3$ |
| **Max fill surface area** | 20,420 sqm | 27,930 sqm | 11,300 sqm |
| **Side slopes** | 1:3 | 1:3 | 1:3 |
| **Clearance** | NA | 3 m from properties | 3 m from road |

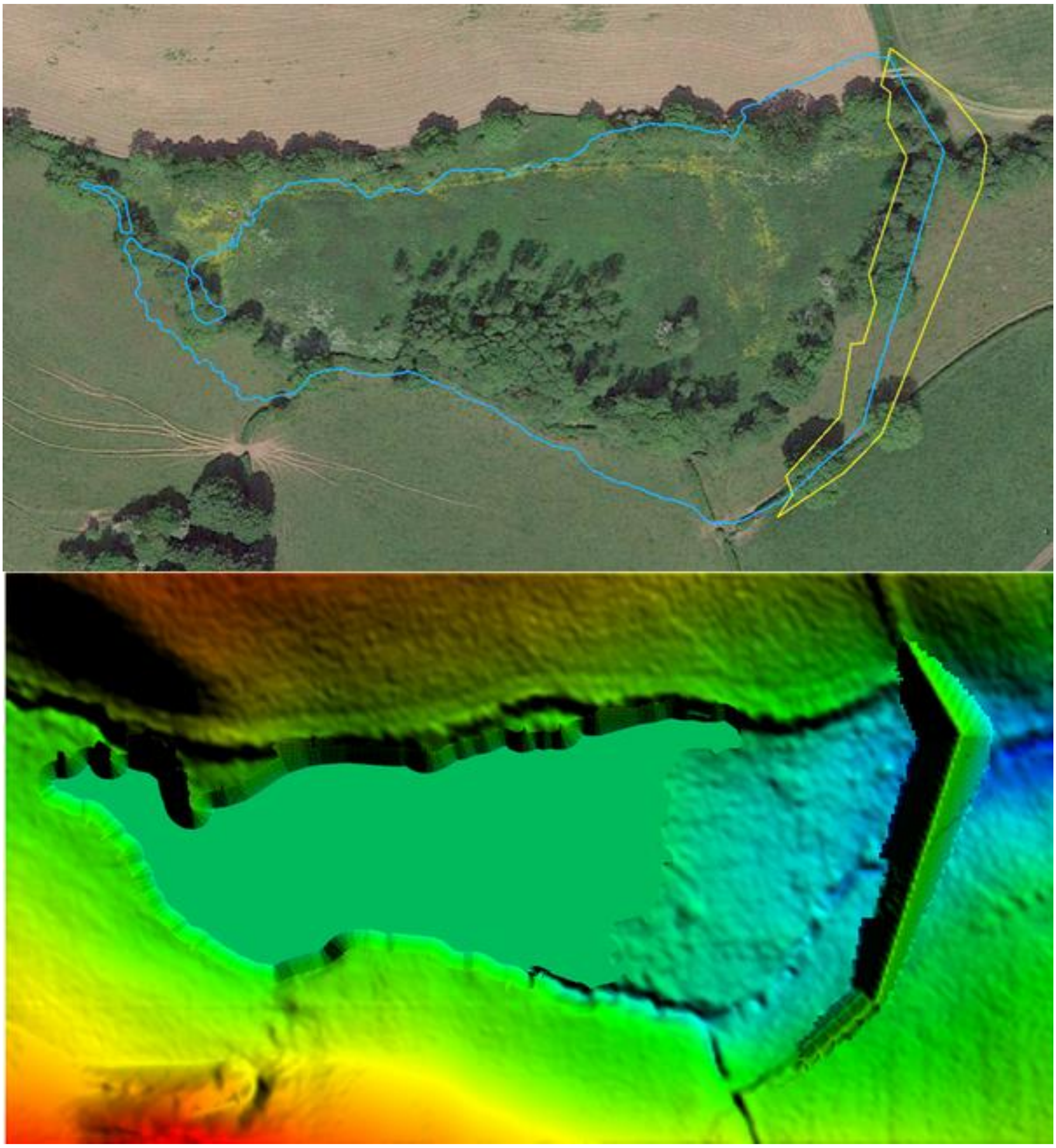


Figure 13: Marsh attenuation storage area

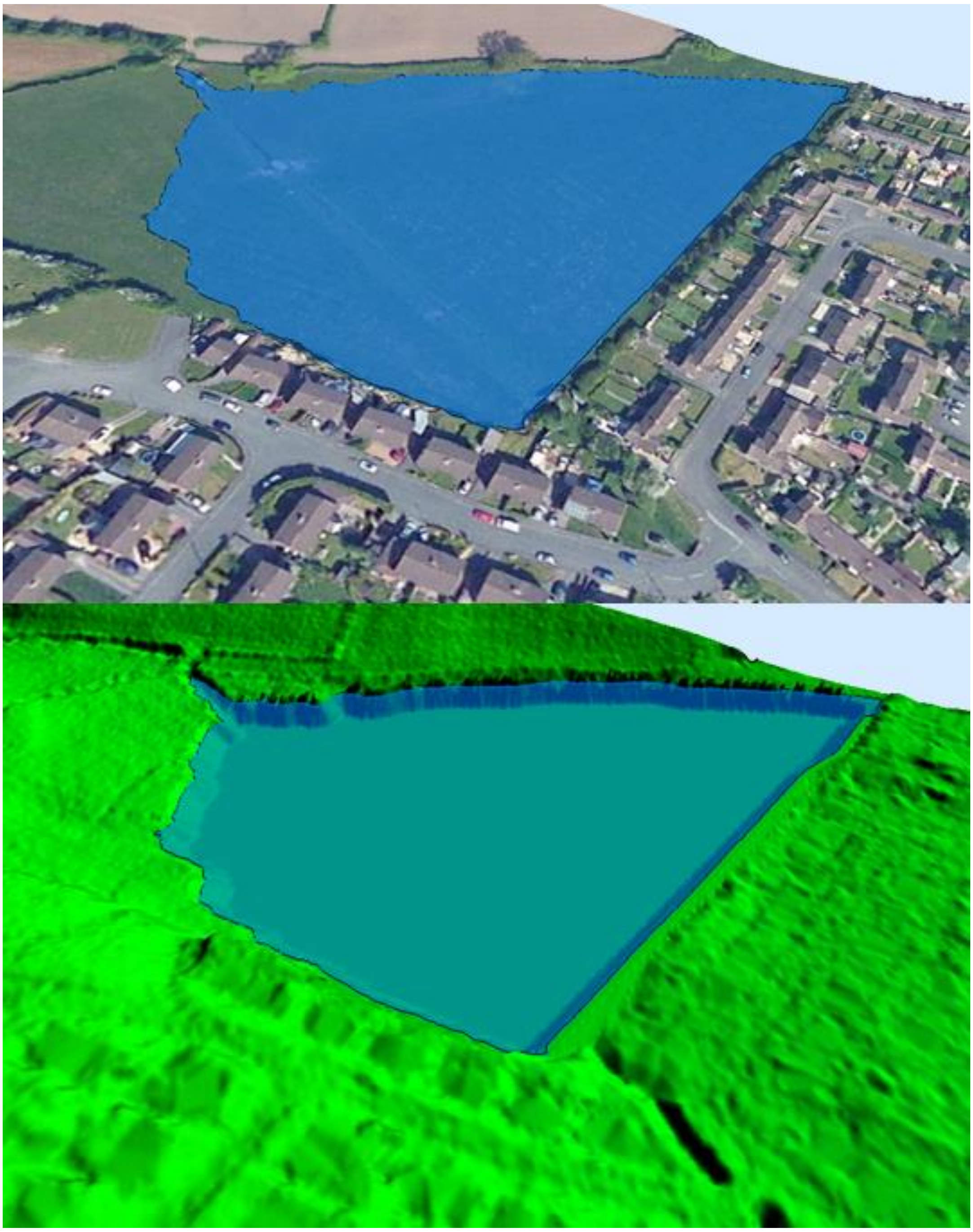


Figure 14: Queens Park attenuation storage area

Figure 15: Ruthin Road attenuation storage area

Catchment 'I', Fir Grove, could be problematic for active storm storage. A possible solution is a deep storage tank near Fir Grove with pumping or a gravity flow to the River Alyn catchment a little further north. This would take in about 70% of the catchment area, the remaining being in urban Mold.

The assessment confirms a healthy mix of potentially developable attenuation storage areas to alleviate flood risk to Mold.

These attenuation storage areas can be developed in a way that also provides benefits of Natural Flood Management whilst being 'smart'. The storages will be activated only for short periods of few hours to 'catch the peak' and therefore the land will still be available for their existing land-use.

These attenuation storages can capture and attenuate a significant amount of peak flood volume previously planned to be intercepted by the present FAS proposed cut-off drain. The works would need some significant earthworks but appear entirely feasible and very cost effective.

## Smart FM implementation

Appendix A shows a chart utilising the full Smart FM on the three Gwernaffield potential storages and one Gwernymynydd storage. In this arrangement, the Fir Grove flows are exported to the River Alyn.

### Gwernaffield catchment

The Gwernaffield catchment is the largest catchment and under certain conditions has the potential for much higher flows than expected. It is therefore important that more than one storage site be considered. If the upstream ravine storage is suitable it would have a set of activated gates and a series of storage bunds. For control simplicity all gates in a storage site would activate from a single command and not act independently. A level sensor on the lower bunded store and a flow outlet gauge would determine the input and output conditions of the system. Similar considerations apply to the downstream storages of the Marsh and Queens Park. Depending on further investigations, a transfer function (TF) model of each storage can pass data so that the three models run in a chain and each set of storage gates can operate independently. If it is found that one TF model can be used for the whole catchment and the gates can be controlled in unison then the simpler solution would be implemented.

As a rainstorm arrives over the combined catchment, three rain gauges would send data combined to a representative value to the input of the TF model. The model once calibrated would be operating in forecast mode and the storage gates would be throttled down to collect water close to the peak of the storm. Given a suitable clear forecast by the TF model rain gauge input, the stored water would be released later at a rate suitable for the capacity of Mold's urban drainage culverts.

Loss from the Milwr tunnel would be incorporated in the general TF model without a separate investigation.

### Gwernymynydd catchment

The storage would have multiple gates and in this instance they would be controlled separately by commands from the TF model forecast, such that the lowest pond gets filled first. A level sensor and flow sensor outlet gauge determine the operating conditions for input to the TF model. This catchment is small and may have short response time. If the forecast lead time using the TF model is too short it could operate on a simpler level controlled storage – this option would be investigated during initial TF calibration and site instrumentation.

### Catchment ‘I’, Fir Grove

Catchment ‘I’, Fir Grove, would require a level sensor for pump activation and could essentially be passive, though flows should be investigated during the whole catchment calibration period. As long as flows were exported out of the catchment and into the River Alyn catchment, it can act independently.

### Rainfall data

Rainfall data for the catchment can be measured using tipping bucket rain (TBR) gauges when a suitable site is available or by using piezoelectric rain gauges if the site is prone to leaf fall and debris. TBR gauges are often used in pairs to increase data reliability and reduce maintenance visits. Three pairs of TBR gauges or three piezoelectric gauges is the minimum number needed to cover all catchments. The rainfalls across the catchments are similar; both have a SAAR of about 900mm, a modest annual rainfall total.

## Cae Bracty

Cae Bracty, located in a natural topographic depression is at risk of frequent flooding from the rain falling directly over the town. It is one of the most problematic areas at risk of flooding in Mold. The suggestion has been made that it may be more cost effective to demolish these properties and rebuild them at a higher level. However, this study will focus on possible ways of saving the properties, while reducing flood risk to a more tolerable level.

### Upstream Interventions

Storage on the Gwernaffield and Gwernymynydd catchments, as well as diversion of Fir Grove water has the potential to reduce flows to allow excess Cae Bracty water into the culvert. This may be a long term solution, but it appears likely that in the short term this area can be removed from significant flood risk in a cost-effective manner more locally.

### Local overland flow diversions

There does not appear to be much scope for urban overland flow diversions, particularly along highways from the steeper SW direction (Bryn Coch direction) Although this could route incoming water around the Cae Bracty depression it might simply shift the problem elsewhere.

### Infrastructure improvements

In addition to possible pipe network infrastructure improvements discussed previously; if the ‘dam’ caused by the raised road levels along Brook street and at the Wrexham Road off the Cae Bracty depression can be ‘bypassed’ by laying a pipe beneath (that only operates in storm conditions), the current storage will be far more effective.

### Improving the current storage

Utilising the existing storage but with Smart FM to stop the storage filling too early, from minor storms before a major storm, has its merits. If the bottleneck can be opened by other improvements, as described, then Smart FM peak flow lopping can be used to optimise the use of the existing storage.

Storage could be increased (beyond the current 40m3 tank capacity) by installing additional tanks in the nearby playing fields. This would require further investigation of the potential volumes that can accumulate in the Cae Bracty depression during storm conditions. Increased storage provision is likely to require pumping – but this could be restricted to just extreme events and only for the duration of peak flow lopping.

### Individual property flood protection

Flood proofing two or three of the lower level properties would increase above ground storage. Smart FM system operating on culvert/storage tank levels would inform residents (by phone. text or email to move vehicles and install their doorway flood defences in good time.


Figure 16: Pumping station at Cae Bracty

Exploration of green infrastructure in the town may also help alleviate some of the flood risk whilst providing additional social and environmental benefits. Such measures are also likely to help unlock additional funding.

## Catchment diversions

It is understood that wider scale modelling of the River Alyn undertaken by NRW has confirmed that there is capacity in the River Alyn to receive additional flow.

Therefore, although substantial attenuation storage options in the upper catchments seem achievable, any residual flows to ensure the required standard of protection to the properties and businesses in Mold may be diverted to the River Alyn. This can be achieved by either constructing a diversion channel/culvert or a directional drill diversion tunnel or a combination of a channel and a tunnel as shown in Figure 17.

In engineering hydrology, cut-off channels are well known to be an excellent method of diverting or capturing unexpected flows during more extreme events. Cut-off channels have less potential for blockages compared to culverts, however, they are seen by landowners as intrusive. Less intrusive culverts still require cut and cover construction but directional drill tunnels are a low intrusion option.

The advantage of adding flood storage to the catchments' diversion plan is flexibility. Diversion channels, culverts or tunnels can be substantially smaller and shorter. The length of diversion could be as minimal as capturing Fir Grove flows, an intermediate length capturing Gwernaffield and Fir Grove or the original full length capturing all three catchments but carrying smaller flows.

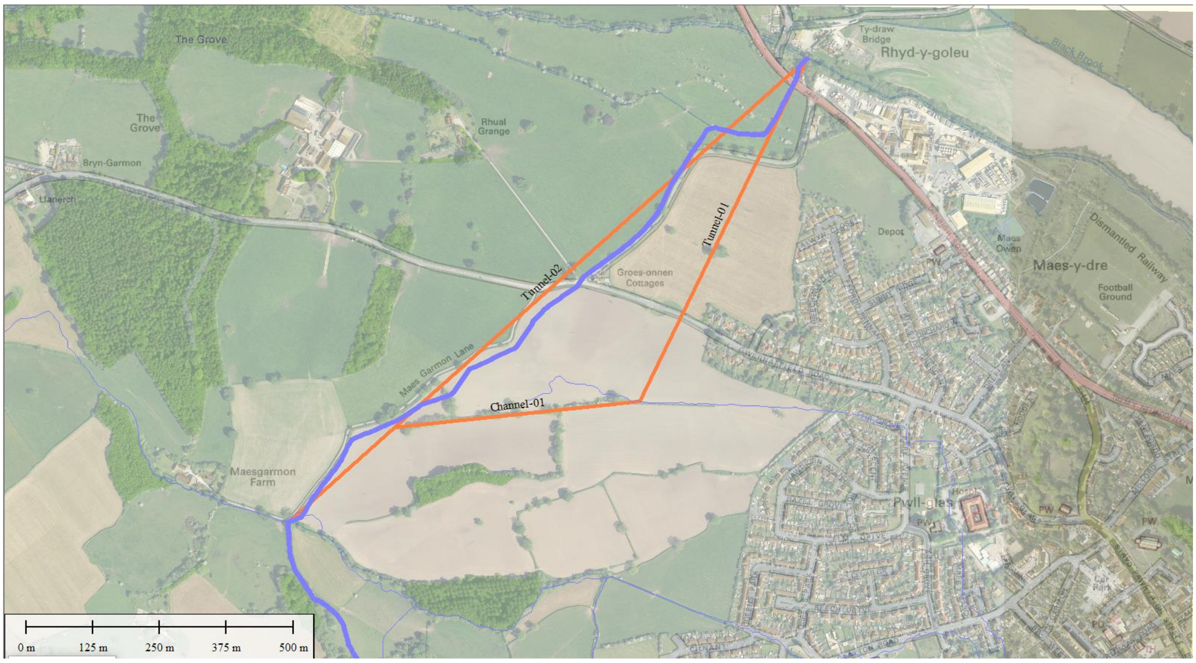



Figure 17: Diversion options for any residual flood flows

Although all diversions discussed drain north to the River Alyn upstream of Mold, there is scope for diversions south of Mold to the River Alyn for the Gwernymynydd catchment in association with attenuation storage at Ruthin Road. An overview of all the potential attenuation storages and diversions for alleviating flood risk to Mold is presented in Figure 18

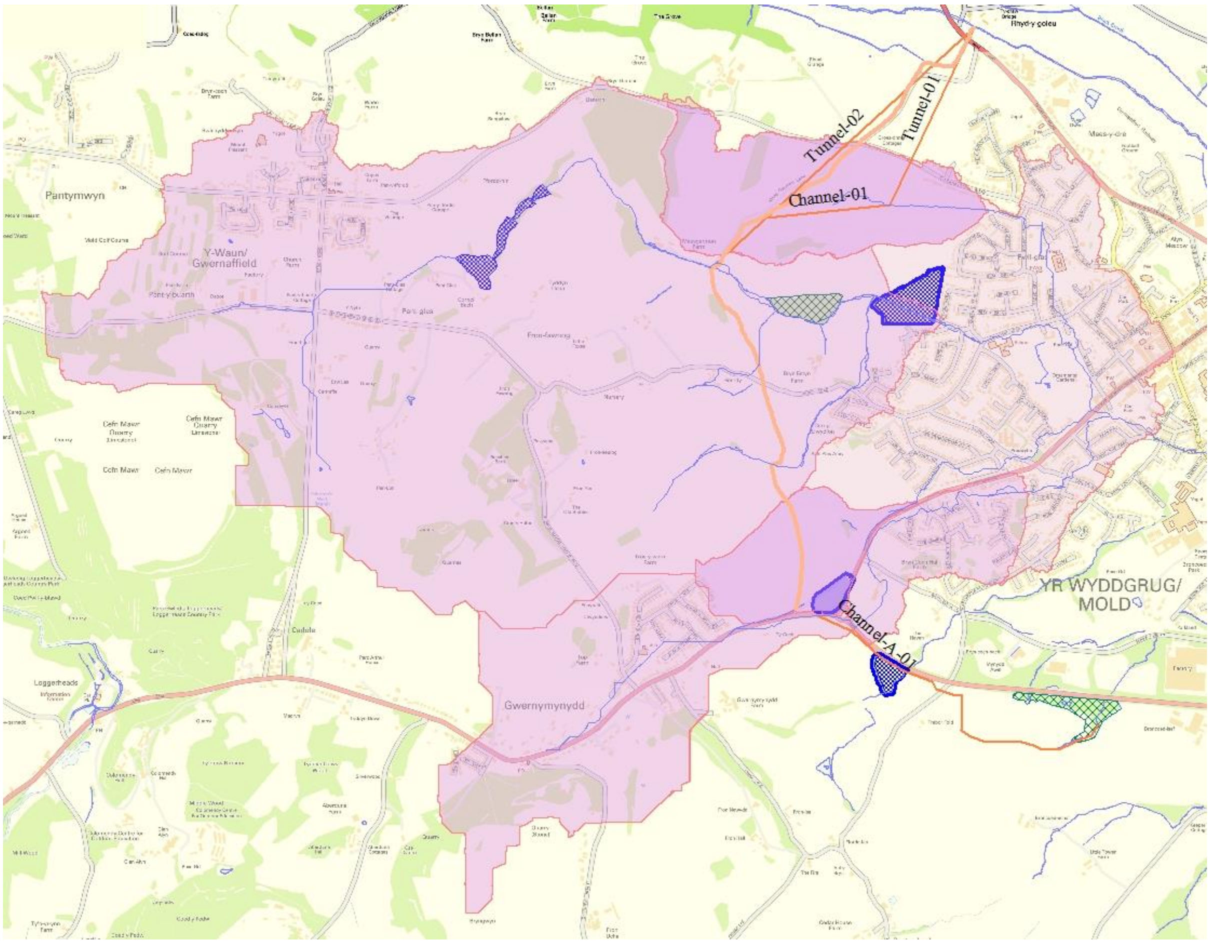



**Figure 18: Overview of all the potential attenuation storages and diversions**

These options have not been explored 'on the ground' as landowner contact would be needed for this but some of the proposed interventions are along the route of the cut-off drain proposed in the present FAS. Nonetheless, land use and mapping has been reviewed and there does appear to be merit in looking further at these options.

However, it has been concluded that a combination of various measures will provide a sound balance here. Keeping storage volumes below 10,000 m3 will reduce both construction cost and ongoing supervisory costs as the storage areas will not fall under the Reservoirs Act. Diverting flow to the River Alyn will take volume out of the Gwernaffield flood flow and installing an additional drain in the urban area from Cae Bracty to Gas lane will reduce flood risk there. This overall methodology is presented on the flow diagram and 'Opportunity Map' included as an appendix to this report.

## Joint working, funding and additional benefits

Joint working with the stakeholders is an important tenet of the SFM / NFM approach. A collaborative process not only identifies the key stakeholders, but also provides vital support and information necessary for the success of a flood scheme. An additional benefit of the collaborative process is that it may identify additional funding sources by matching the plans and objectives of the key stakeholders with those of the potential options for a flood scheme.

Flintshire County Council and DCWW are the key relevant stakeholders keen to solve flooding issues in Mold. Therefore, it is suggested that this Smart Flood Management feasibility study be used to initiate a FCC-DCWW partnership; and then additional stakeholders can be approached for their involvement and support.

With the uncertainties associated with any hydrological assessment compounded by the impact of climate change, there is a clear need to add a factor of safety. The attenuation storage areas can be sized to accommodate more extreme exceedance events. Green infrastructure measures (hedge and tree planting in particular) - both around the storage areas and in the catchment generally - should be explored to provide further flood risk reduction benefits to counter uncertainty. Furthermore, Green Infrastructure will further enhance the environment by improving water quality, air quality, biodiversity and other benefits.

The above methodology focusses on solutions and outcomes. Refining and documenting the process will make it readily transferrable to other catchments.

The cascade storage at the roundabout could be landscaped to be visually attractive and at the very least an improvement on the tip scene that presently greets visitors to Mold. At best it could be iconic.

Social gains will be obtained from dealing with the depressing frequency of flooding at Cae Bracty and some properties could be brought back into use.

Biodiversity gains should be possible at the marsh area which is presently almost derelict

Listening and engaging with landowners, as opposed to imposing something on them they disagree with, will bring about enthusiasm and support and ensure the project is delivered quickly and cost effectively.

## Conclusions

This study has explored feasibility of Smart FM alternatives to the cut-off flood relief channel proposed in the earlier FAS. Building on previous data, hydraulic models, and local knowledge of the catchments the exploratory work undertaken has identified a number of Smart FM options available to alleviate flood risk issues in Mold, with the most promising ideas being as follows:

1).There is a significant drainage constraint at Cae Bracty where two 850 mm drains and one 600mm join together, but the combined outlet is still only 800 mm diameter. The cost of a new dual pipeline will be high, but the benefits to the system and to Cae Bracty in particular will be significant. The practicality of installing a new pipeline down Brook Street and crossing the Wrexham Road into Gas Lane should be investigated.

2).In the meantime the risk to the properties in Cae Bracty appears unreasonable and a short term remedy which will be compatible with (1) above to provide greater long term protection will be to install Individual Property Flood Protection at the entrances to the lower lying properties and install new Smart controls to the storage tank and pump back arrangement. In the event that item (1) above proves to be too costly another possible solution at Cae Bracty will be to install additional pumped storage beneath the nearby playing fields.

3).Two flood attenuation areas have been identified as being viable with Smart FM controls to make the storage volumes useful. It should be highlighted that these would need to be significantly larger storages if Smart FM is not used. Flows from the Gwernymynydd area can be attenuated at the Ruthin Road Roundabout while the Gwernaffield flows can be attenuated at a 'marsh area' upstream of Queens Park. There is also a valuable attenuation potential on the edge of Queens Park, but this could be within the envelope of future urban development. The imperative there will be to ensure flood attenuation forma part of any development proposal. A small scheme also needs to be developed at Fir Grove.

4).Due the nature of the soils in the Gwernaffield catchment, flows could be higher than predicted by current ReFH software. Some caution and contingency is therefore warranted and the potential for diverting flow directly to the River Alyn should be investigated with landowners. By not having to collect from Gwernymynydd the ditch could be smaller and routed to avoid the Alwen Aqueduct (which was an impediment to the orginal scheme).

Overall the conclusion has been reached that a combination of interventions will provide the best and most cost effective solution as shown in the appended flow diagram. Subject to detailed modelling, design and early stakeholder engagement this approach should significantly outperform the cut-off channel proposed in the current FAS on constructability, affordability, reliability and sustainability criteria and bring the schem back within the original budget.

The appended 'Opportunity Map' is supplemented on the next page by an Action Plan, with broad cost estimates below. Recommended strategic next actions then conclude the report.

## Action plan and budget costings

| Stage | Description | Budget est. |
|---|---|---|
| 1 | Installation of individual property flood protection at Cae Bracty, together with implementing Smart system to control tank storage and pump back operation | £200 k |
| 2 | Engage with landowners; prepare full working details of storage alongside Gwernymynydd / Wrexham Rd roundabout; implement a Smart FM scheme; and allow for ongoing maintenance | £1000 k |
| 3 | Engage with landowners; prepare full working details of storage in the marsh area upstream of Queens Park; implement a Smart FM scheme; and allow for ongoing maintenance | £700 k |
| 4 | Engage with landowners; prepare full working details of diversion ditch and associated culverts and install to NRW requirements | £1100 k |
| 5 | Engage with landowners; prepare full working details of storage in the area upstream of Fir Grove; implement a Smart FM scheme; and allow for ongoing maintenance | £400 k |
| 6 | Investigate and engage with DCWW and construct new 800mm diameter pipeline from Cae Bracty to Gas Lane (including directional drill under Wrexham Road). Alternatively install additional tank storage beneath playing fields opposite Cae Bracty. | £1600 k |
| 7 | Engage with landowners; prepare full working details of storage alongside Mold Bypass to counteract climate change flow increases; implement a Smart FM scheme; and allow for ongoing maintenance | £500 k |
| 8 | Ensure that any future planning application for the land alongside Queens Park takes account of the valuable flood attenuation storage opportunities that exist (funded under Section 106 by developer). | nil |
| | Broad budget total | £5.5 million |

## Recommended Strategic Next Actions

1. Submit a copy of this report to Welsh Government to confirm the Smart FM approach is acceptable in principle; and that grant funding on the basis of a budget of £5.5 million is available. Agree a phased delivery programme.

2. Undertake a topographical survey of Cae Bracty, obtaining threshold levels and details of property drainage. Obtain prices for supplying and installing Individual property flood protection (IPFP) to affected properties (including non-return valves on drains and protection to air bricks).

3. Liaise with DCWW and obtain details of the existing drainage arrangement in the vicinity of the existing Cae Bracty storage tank and the pump back system. Prepare details of a (Smart) automated system that makes most use of the existing storage in conjunction with IPFP. Investigate whether DCWW might contribute to the cost of these works.

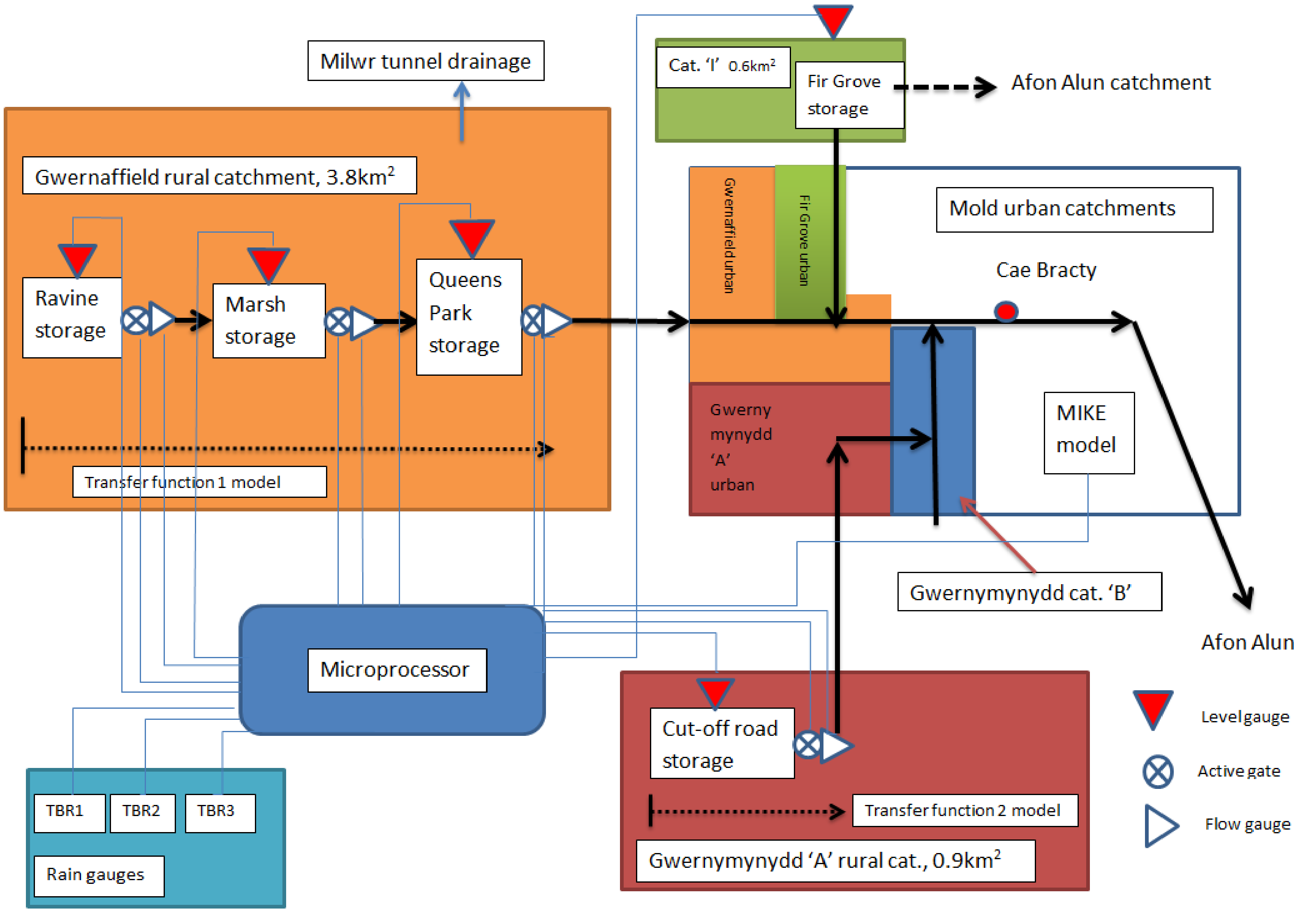
4. Undertake a topographical survey of Brook Street / Wrexham Road / Gas Lane together with existing drainage and all utility apparatus. Prepare a scheme to install a new drain to carry flood water from Cae Bracty to Gas Lane. Undertake a modelling assessment downstream to ensure no undue adverse impact of passing forward flood water flows. Obtain tenders for the works.

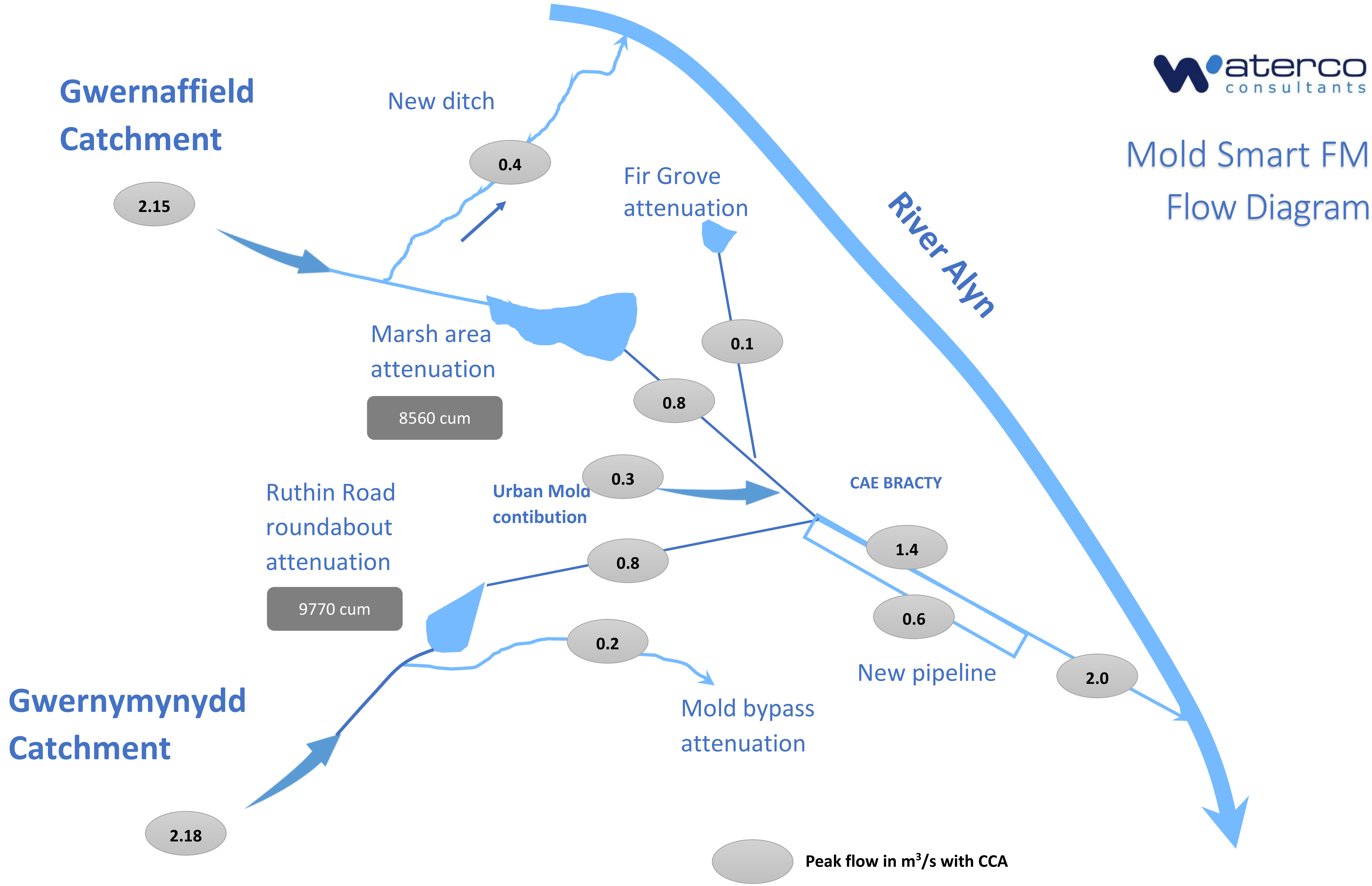
5. Engage with landowners, undertake topo and ecology surveys and develop schemes for Smart FM attenuation (in sufficient detail to obtain cost estimates) at three locations:

   - Gwernymynydd/Wrexham Rd roundabout
   - Marsh area upstream of Queens Park
   - Edge of the Fir Grove Estate

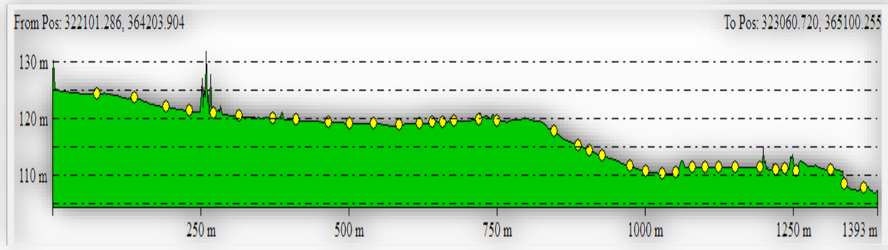
6. Engage with landowners and investigate the viability of a ditch (similar route, but smaller in size that the original FAS and avoiding Alwen Aqueduct) to the River Alyn; to divert water from the Gwernaffield catchment and improve the standard of flood protection.

7. Ensure that any future planning application for the land alongside Queens Park takes account of the valuable flood attenuation storage opportunities that exist. Work with developers under a Section 106 Agreement to obtain some degree of ‘betterment’, i.e. storage volume over and above the standard greenfield run off associated with any development


Milwr tunnel drainage
Cat. 'I' 0.6km²
Fir Grove storage
Afon Alun catchment
Gwernaffield rural catchment, 3.8km²
Gwernaffield urban
Fir Grove urban
Mold urban catchments
Cae Bracty
Ravine storage
Marsh storage
Queens Park storage
Gwerny mynydd 'A' urban
MIKE model
Transfer function 1 model
Gwernymynydd cat. 'B'
Afon Alun
Microprocessor
Cut-off road storage
Level gauge
Active gate
Flow gauge
Transfer function 2 model
TBR1
TBR2
TBR3
Rain gauges
Gwernymynydd 'A' rural cat., 0.9km²


Mold Smart FM
Flow Diagram
Gwernaffield Catchment
2.15
New ditch
0.4
Fir Grove attenuation
River Alyn
0.1
Marsh area attenuation
8560 cum
0.8
0.3
Urban Mold contibution
CAE BRACTY
Ruthin Road roundabout attenuation
9770 cum
0.8
1.4
0.6
0.2
New pipeline
2.0
Mold bypass attenuation
Gwernymynydd Catchment
2.18
Peak flow in m³/s with CCA

# Mold Flood Alleviation Scheme
# Smart Flood Management – Opportunity Map




**Proposed new ditch profile** – with localised culverts to divert flow alongside Maes Garmon Lane directly to River Alyn

4

**Queens Park –** attenuation with any future development

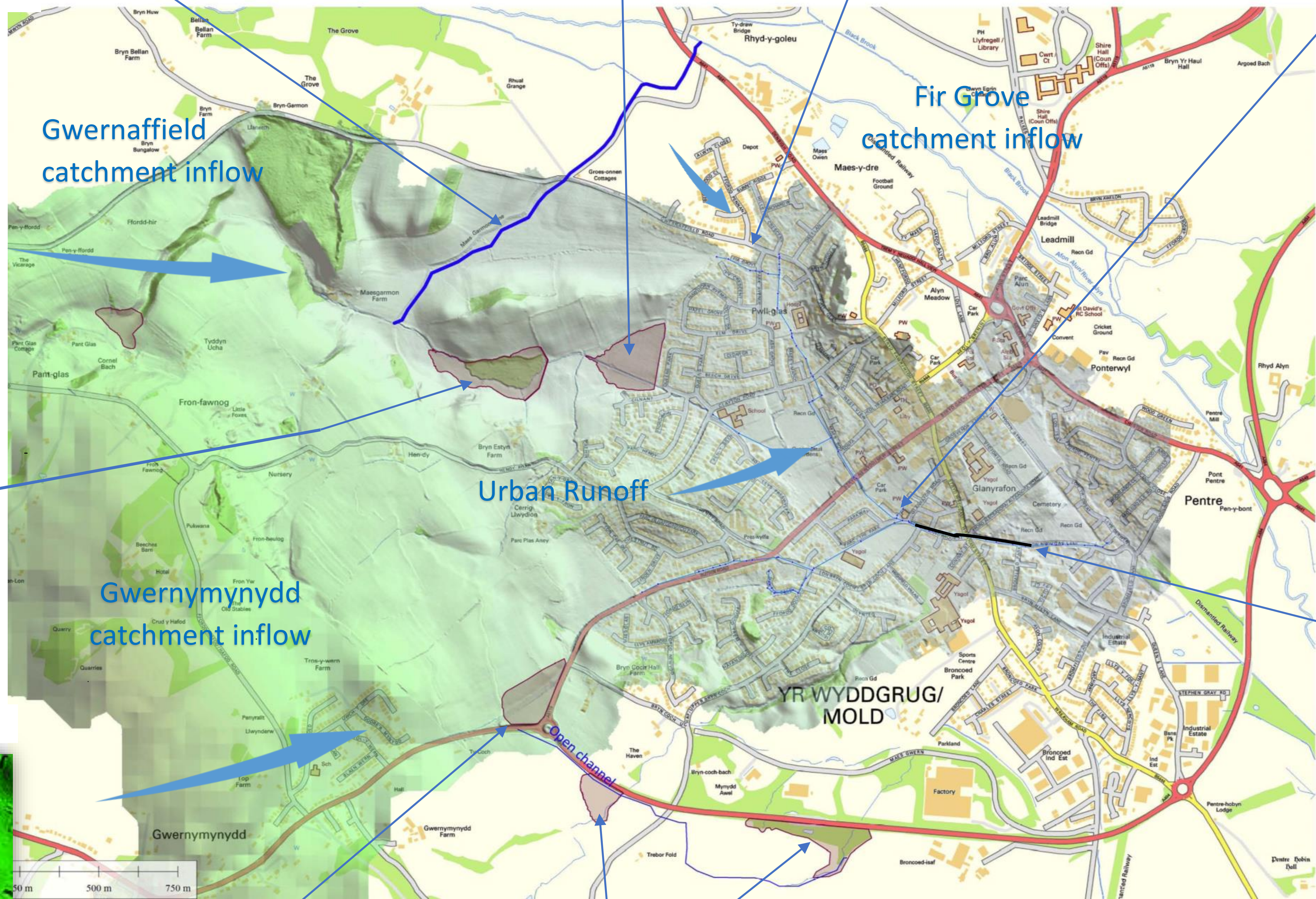
8

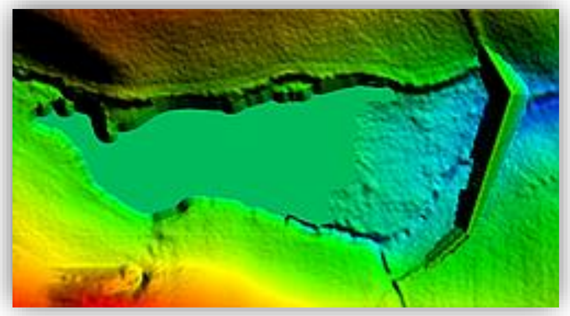

5

**Fir Grove –** proposed attenuation And storm pumping station

1

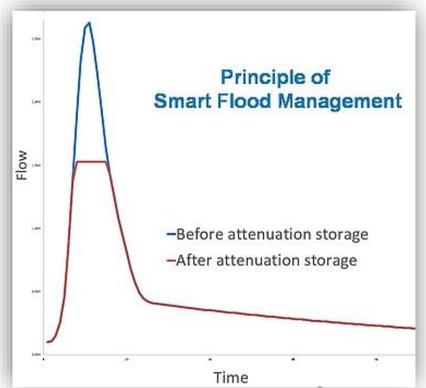
**Cae Bracty –** proposed individual property flood protection and addition of Smart controls to existing storage tank and pump.



**Marsh Area –** proposed attenuation Volume <10,000 m3

3

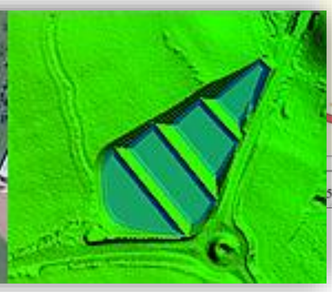



6

**Brook St.to Gas Lane storm relief** proposed new pipeline parallel with existing 900 mm storm drain

Aerial image

Concept plan of cascades



**Gwernymynydd / Ruthin Road roundabout** proposed attenuation in 4 cascade pools Volume <10,000 m3

2



7

**Land alongside Mold bypass** With potential for additional attenuation areas to offset climate change.

#

**Proposed Order of Implementation**