THE DEVELOPMENT OF A 'TWO TIER' DISCHARGE CONSENT FOR CRIGGION QUARRY, SHROPSHIRE

***L. Clarke*[1], *J. Dodds*[1], *H. Mayfield*[2]**

[1]*Envireau Water, Cedars Farm Barn, Draycott. DE72 3NB*

[2]*Hanson Quarry Products, Clifford House, Wetherby. LS22 7NS*

Abstract

This paper describes the development and assessment of, and successful application for a two tier discharge consent for gravity drainage from a severely space limited dolerite quarry (Criggion Quarry) on the River Severn floodplain, in Shropshire.

Rainfall runoff at the quarry has the potential to generate a very high suspended solids load. This, together with an outdated and inappropriate discharge consent, resulted in historic problems with discharge during intense rainfall events and regulatory compliance concerns.

In discussions with the Environment Agency regarding the updating of discharge consent conditions, an upgrade of the drainage management system was agreed to provide improved attenuation and settlement times for the surface water runoff and to separate clean water from dirty water. This was coupled with refurbishment and dredging of nine pre-existing lagoons and settlement areas along with the development of eight new settlement and seepage lagoons.

Due to unique drainage circumstances and the location of the quarry in relation to the River Severn floodplain, a tiered approach to two new discharge consents was agreed with the Environment Agency. The nature of the discharge was to depend on "normal" or "high intensity storm event" weather conditions (> 1 in 30 year storm events).

The improved drainage system is capable of attenuating storm events up to and greater than a 1 in 100 year 24 hour storm whilst maintaining discharge rates at or below the Greenfield Runoff Rate.

The improved drainage system is also capable of allowing settlement of suspended solids to below 80mg/l up to and including the 1 in 30 year 24 hour event. However, for events greater than the 1 in 30 year 24 hour event, the suspended solids load will increase beyond 80mg/l, but will be compliant with the new discharge consents (Environmental Permits).

Clarke, L.E., Dodds, J.E., and Mayfield, H. 2010. The development of a "Two Tier" discharge consent for Criggion Quarry, Shropshire. Pp. 115-123 in Hunger, E. and Walton, G. (Eds.) Proceedings of the 16th Extractive Industry Geology Conference, EIG Conferences Ltd, 194pp.

e-mail: leeclarke@envireauwater.co.uk

Introduction

Criggion Quarry has been operating for many decades and has grown and developed over that period. Due to the location and nature of the quarry, there has been a long history of water management issues, particularly during intense rainfall events that could generate a severe suspended solids load that has the potential to enter into the local watercourse.

The quarry has two consented discharge points. These consents and their conditions were originally issued in 1964. Following a period of regulatory quiescence, the first consent was re-issued in September 1995 by the National Rivers Authority and the second consent was re-issued in April 1999 by the Environment Agency. However, despite re-issuing, both consents remained essentially the same as per the original 1964 consents.

Due to the nature of water management issues at the quarry leading to regulatory compliance concerns along with the history of past consenting, it was recognised by both Hanson and the Environment Agency that both consents needed revising and modernising.

The quarry is a restricted site with a very small foot print. There is no potential to usefully increase land area and only limited space within the foot print to improve the water management system. The form of the quarry is that of a "cut – in" i.e. the quarry is removing stone from the top and side of a hill. As such water cannot be captured and stored within a deep sump or low bench level.

To resolve regulatory compliance concerns, two options were available:

1. Expensive mechanical de-silting and dewatering probably in excess of £1,000,000 capital investment.
2. Undertake improved on site water management with a view to:
   - Separate clean water from dirty water (natural runoff from quarry derived flow).
   - Attenuate flows as high on the quarry as possible to reduce velocities and the suspended solid load.
   - Improve flow balancing and reduce velocities in final settlement areas.
   - Intercept uncontrolled "dirty water" runoff prior to entering the local watercourse.
   - Improve settlement pond management.
   - Revise, modernise and negotiate an appropriate discharge consent structure.
   - Expected cost £200,000 to £500,000.

Description of Quarry

Criggion Quarry is located approximately 9km to the north-east of the town of Welshpool. The quarry is centred at grid reference SJ 289 143 and elevations across the site vary between 61 and 345mAOD (Figure 1). The main quarry area is located on the north western slopes of a steep hillslope. The hill is part of the Breidden Hills, a dominant feature on the surrounding landscape as the hills protrude out from relatively flat, low lying land associated with the River Severn floodplain. The Breidden Hills are composed of submarine volcanic accumulations consisting of volcanoclastic conglomerates and sediments and also several dolerite sills. A thick olivine-dolerite laccolith is exposed at the Quarry. There is a well developed fracture network within the rockmass. The primary output from the quarry is aggregate for road wearing courses and special construction projects (e.g. Armour Stone).

Drainage from the quarry flows to an Internal Drainage Board (IDB) drain called the Acre Brook via two discharge points (Figures 1 and 2). The IDB drain flows into the River Severn approximately 2km to the east-north-east of the site. The quarry can be divided into several sub-catchments and drainage courses that have gradients ranging from 0.4° to 70°. The site consists of wooded areas, scree deposits, the actual quarried area, haulage roads, lagoon areas and hard standing areas comprising buildings and processing plants.

Hydrogeology

The rest groundwater levels at the site are associated with the sediments of the River Severn floodplain and therefore, the quarried portion of the laccolith, above the floodplain area, is unsaturated. Flows through the bedrock are dependent on the percolation of rainfall through fracture pathways.

Observations at the quarry during heavy rainfall suggest that the vast majority of rainfall on the quarried area infiltrates into the ground to become flow in the bedrock unsaturated zone. It is suspected that this is due to both natural and blast induced fracturing observed at the quarry. Additionally, there appears to be very little runoff from the wooded scree slopes despite the steep gradients, which also indicates that a large majority of rainfall is infiltrating. The result of this infiltration is to reduce and delay peak runoff and reduce the total runoff volumes.

No springs, seepage faces or "exit" points from the laccolith were found. Therefore, it is hypothesised that surface runoff that enters into the laccolith, then percolates into the groundwater system associated with the River Severn floodplain.

Hydrology of the Quarry

The site is set in an area of moderate rainfall, with a long term average annual rainfall of 737mm. The catchment of the site is relatively small at approximately 65 hectares (Figure 2). Approximately one third of the catchment is wooded areas on steep slopes that are composed of scree deposits. Approximately one quarter of the catchment comprises the actual quarried area and haulage roads with little cover or rainfall interception, and approximately one third of the catchment is either the stock area or hard standing areas comprising buildings and processing plants, on relatively flat, low lying ground.

The gradient of the slopes at the site range between 0.4° to 70°. The gradients can be grouped into three general ranges depending on land use. The stock and hard standing areas generally have the lowest gradients ranging from 0.4° to 1.9°. The haulage roads have moderate gradients ranging from 4.5° to 12°, and the quarry faces, wooded areas and scree slopes have the highest gradients ranging from 15° to 70°.

Runoff and drainage from the quarry discharges to the IDB drain, located on the River Severn floodplain. The boundary of a 1 in 100 year flood risk zone is located on the north-western boundary of the quarry at the location of the IDB drain. Therefore, there is the potential that flows in the drain may be reversed as floods occur in the River Severn. Continuous stream flow and stage data was collected in the Acre Brook using a Nivus PCM4 ultrasonic flow sensor in December 2006 and March 2007. The data collected showed this to be the case.

Summary of problem prior to improvements

The steep gradients at the quarry lead to rapid runoff and high run-off velocities, resulting in the pick up of a high suspended solids load. The drainage route for the water is essentially along haul roads, and with no active drainage, rilling and sediment erosion result. Vehicle trafficking along the haul roads also lifts suspended solids and exacerbates the problem.

Without amelioration rainfall runoff with a high suspended solids load, would enter the IDB drain at a number of locations:

- Point discharge at both consented discharge positions.
- Uncontrolled discharge during intense storm events directly into the brook.

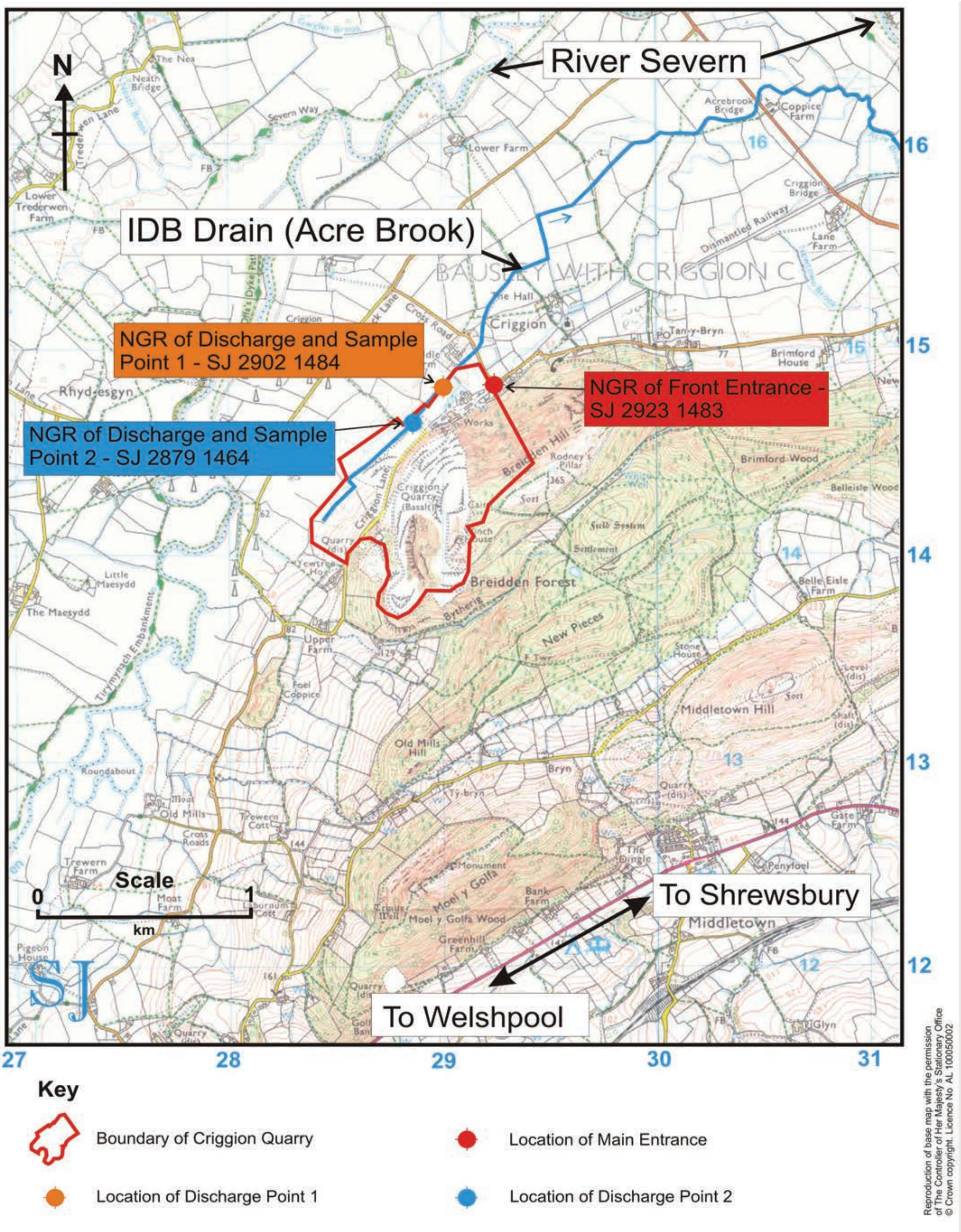

Figure 1 *Location of the hillside, Criggion Quarry.*

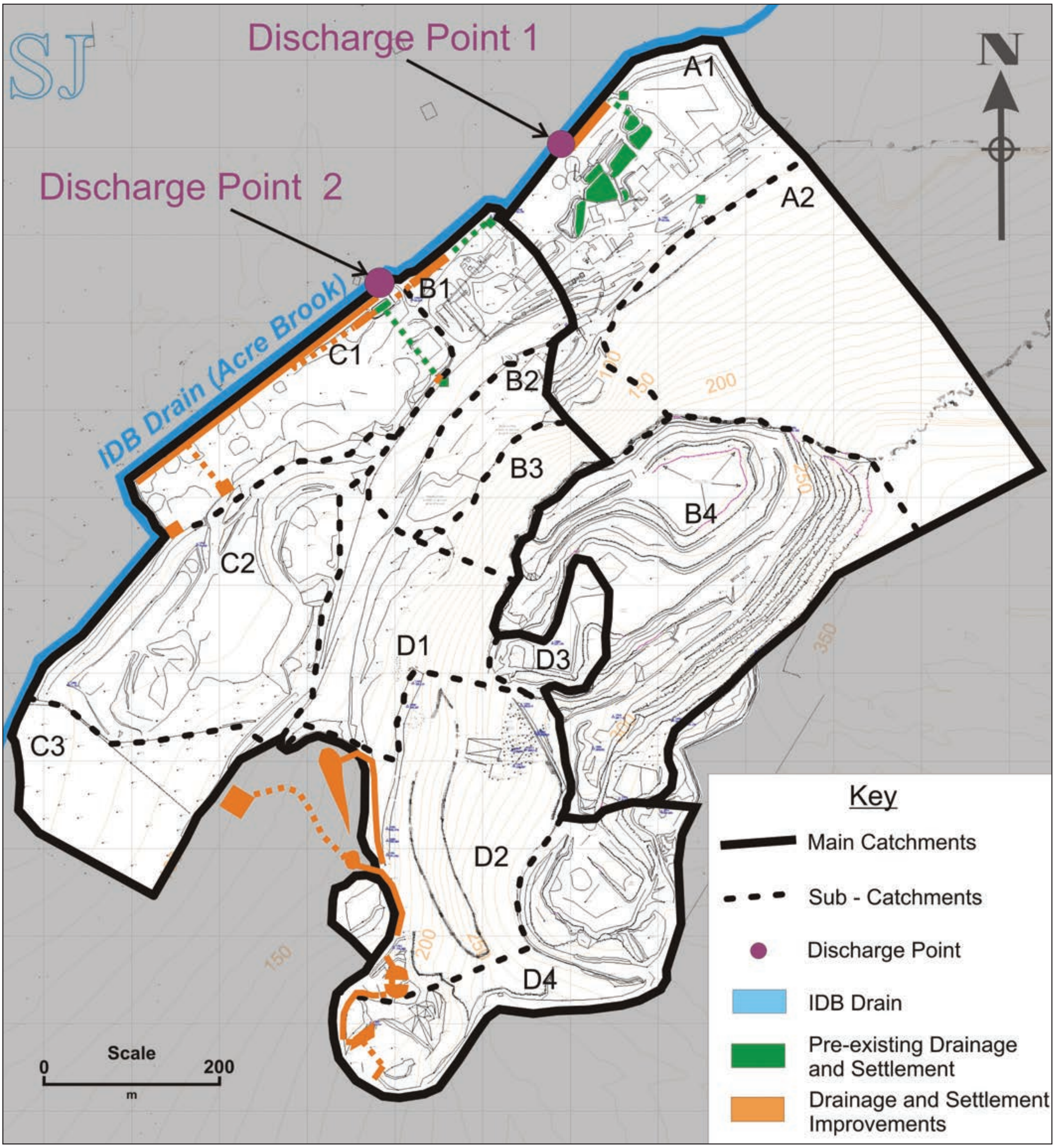

Figure 2 *Site layout, sub-catchments and the drainage improvement strategy at Criggion Quarry shown schematically.*

Water Management concept

Based on topographic and walkover survey data of the quarry, an initial catchment analysis was undertaken along with the identification of clean and dirty water routes. It was recognised that several locations were available for the interception of "dirty water" runoff which could provide water storage and act to reduce runoff velocities aiding the settlement of suspended solids. Figure 3 shows a simplified flow chart for the sub-catchments and drainage routes prior to improvements.

Due to the site foot print restrictions, the reduction in runoff velocities and the separation of clean and dirty water was achieved by a series of small, strategically placed storage and interceptor areas. Figure 4 shows a simplified flow chart for the sub-catchments and drainage routes following improvements. The quarry site was split into two main catchment areas. One catchment that integrated with the existing settlement ponds and water re-cycling system and one catchment with a new lagoon system that removed high velocity runoff from the high slopes and haul roads and also separated out clean water runoff.

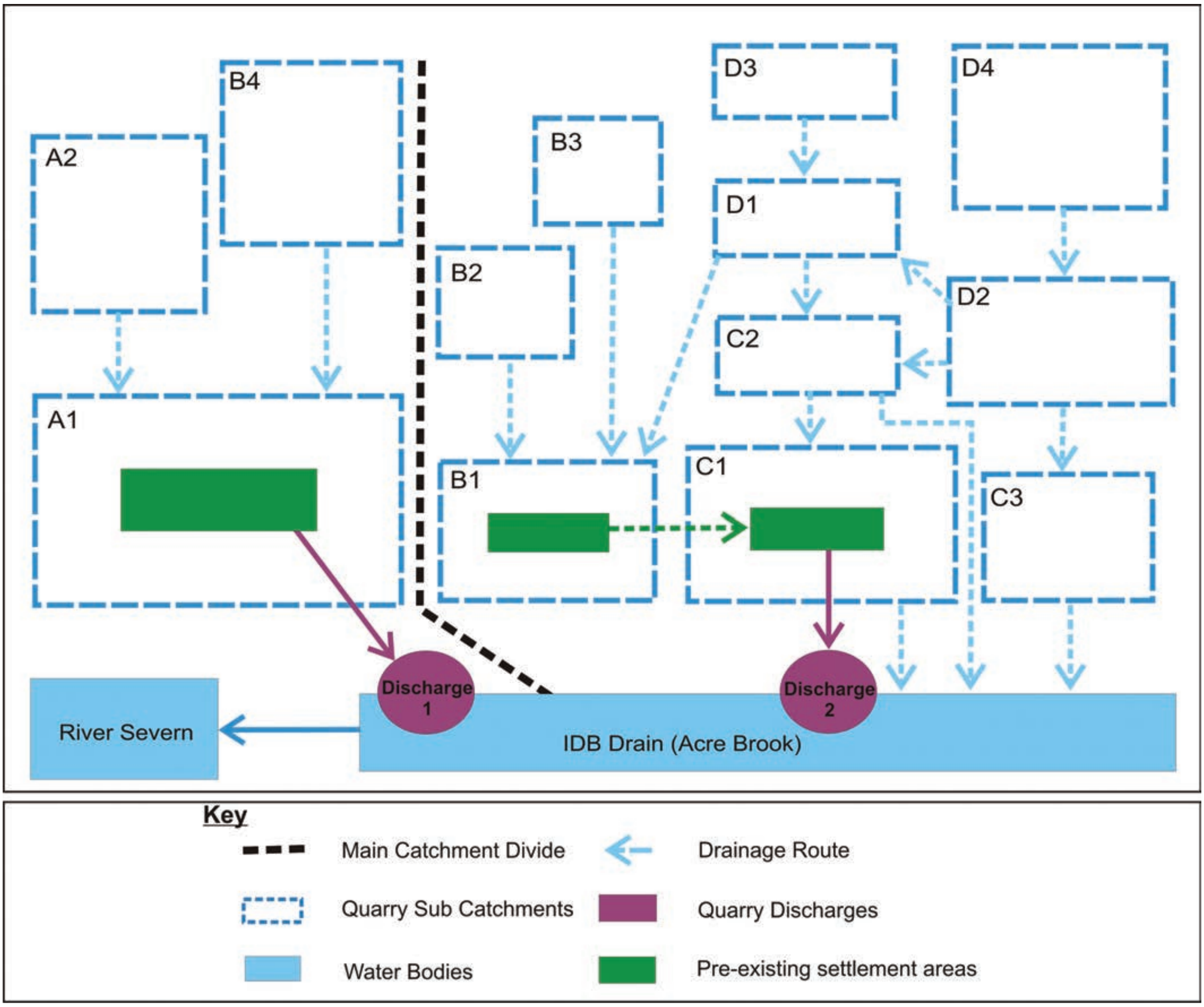

Figure 3. *Flow diagram of quarry sub-catchments and drainage routes prior to improvements.*

The completed works include:

- Eight new settlement and seepage lagoons.
- The refurbishment and dredging of nine pre existing lagoons and settlement areas.
- Two new interceptor drains with strainer walls running adjacent to the IDB Drain to intercept uncontrolled runoff and allow settlement of suspended solids.
- Both of the new interceptor drains were planted with reeds in the final chambers to provide additional polishing of buoyant sediments.
- The re-routing of surface runoff between the existing lagoons / production area and the IDB drain. This intercepts uncontrolled surface runoff before entering the IDB drain and directs flows to the new interceptor drains.
- The routing of haul road runoff to lagoon areas.
- Capture of previously un-captured surface runoff.
- Ancillary connecting infrastructure to direct flows and separate "clean" runoff from "dirty" runoff.
- Energy dissipaters for discharged flows have been positioned at the discharge locations.

The Rational method (a standard hydrological analysis method (Chow V. T, 1988)) was employed to provide a first pass conservative estimate for the sizing of the new settlement lagoons and interceptor ditches based on location, flow routes and catchment descriptors for several sub-catchments within the two main catchments.

Greenfield run-off rates

The value of the Greenfield Runoff Rate (GFR) is critical in the design of runoff control, as it defines the size of attenuation storage required. To provide estimates on the peak GFR for the quarry catchment, IoH 124 [Flood estimation for small catchments (Institute of Hydrology, 1994)], ADAS 345 [the design of field drainage pipe systems (ADAS, 1982)], the Revitalised FSR/FEH rainfall runoff (DEFRA/EA, 2005), and the Rational, methods were employed.

The advice given in the "Preliminary rainfall runoff management for developments" (DEFRA/EA, 2007) is to

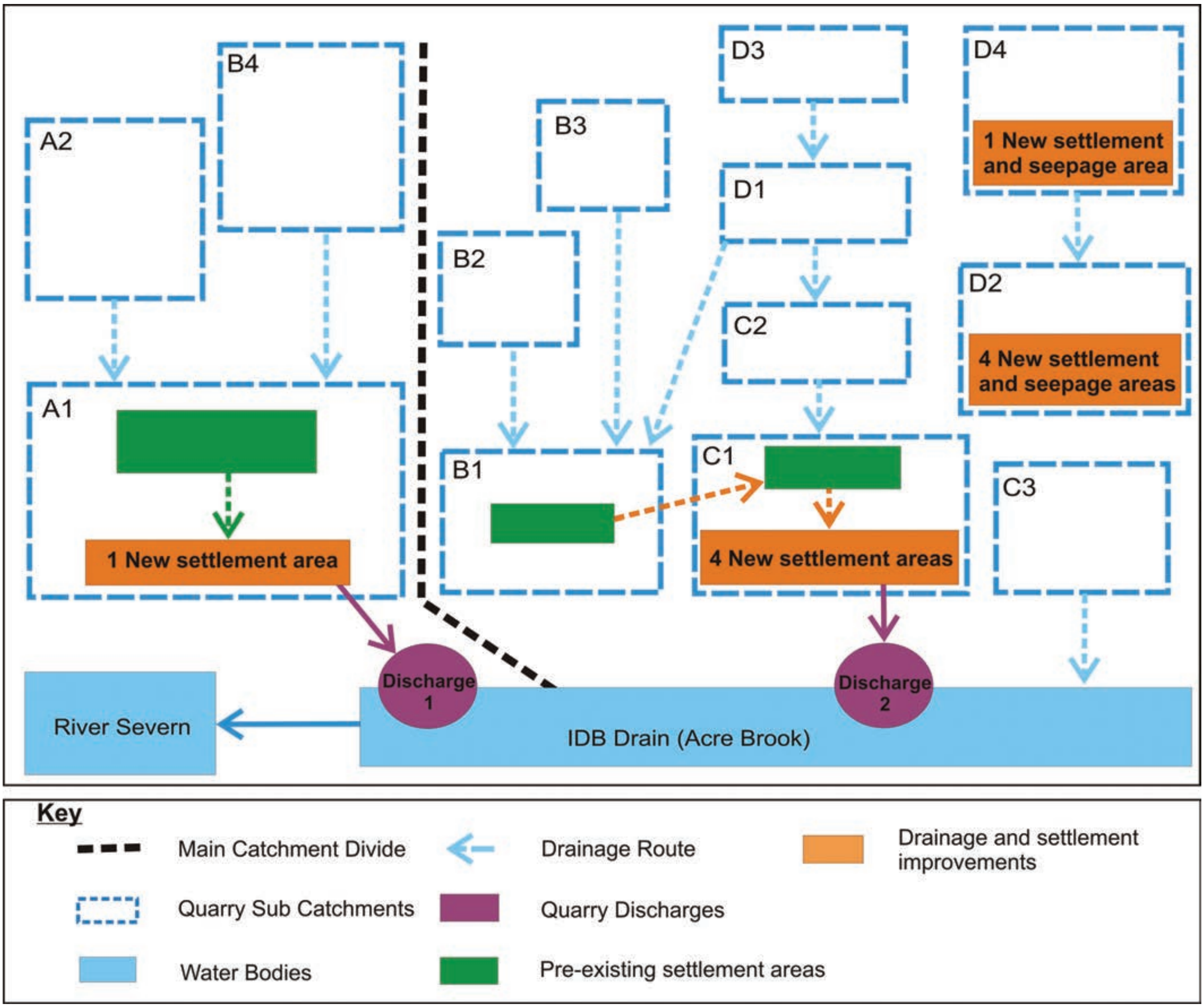

Figure 4. *Flow diagram of quarry sub-catchments and drainage routes following improvements.*

use the flood estimation for small catchments (IoH 124) for the estimation of GFR from catchments of 50 to 200ha. The National Sustainable Urban Drainage Systems (SUDS) Working Group (NSWG, 2004) recommends that the flood estimation for small catchments (IoH, 124) be checked against the design of field drainage pipe systems (ADAS 345), when the catchment area is in the range 30 to 50ha.

To provide a further check, the Revitalised FSR/FEH rainfall runoff method, which was published subsequent to IoH124 and ADAS 345, was employed. This method is applicable to catchments of over 50ha, and incorporates the use of a far wider range of catchment descriptors than the other methods mentioned. The Revitalised FSR/FEH method, is our preferred method for the use on catchments which depart strongly from the norm, as is the case with Acre Brook catchment.

The method employed to estimate the potential run-off volumes for storm events for the drainage strategy, is the Rational Method. Therefore, as a comparison, the Rational Method has also been used to estimate the GFR. The results of the four methods are given in Table 1.

The results of the different methods allow comparison of GFR values and an appropriate value to be selected for ongoing analysis and a basis on which designs can be made. The maximum instantaneous flow rates for compliance were agreed with the Environment Agency to be a GFR of 14 l/s/ha.

Methodolgy	Q100 Greenfield Runoff Rate (l/s/ha)
IoH124	16
ADAS 345	18
Revitalised FSR/FEH	14
Rational	23

Table 1. *Greenfield Runoff Rates for Criggion Quarry using various methods.*

Storage capacity and outflows to the IDB drain

Following assessment of discharges from the quarry and the nature of flows in the IDB drain in relation to the River Severn, it was agreed with the Environment Agency that discharges from the site would be two tiered. The tiering of the discharge was to depend on "normal" or "high intensity storm event" (> 1 in 30 year storm events) weather conditions.

Due to the nature of the site and existing infrastructure two discharge points are required. At both discharge points, "normal" flows exit the lagoon system via a throttled pipe. Set above the throttle pipe is another pipe that becomes operational for events greater than the 1 in 30 year storm.

The Rational Method was employed into an Input-Storage-Output model (ISO Model) to estimate the volume of run-off generated for storm events; and to assess the storage volume requirements for attenuation of peak runoff down to the GFR. Additionally, the surface area requirement to allow sufficient settling times within the lagoon system was calculated, and pipe flow diameters to control maximum discharge rates determined (throttle pipes). Modelling software (Pipe Flow Wizard, 2012) allowed for the sizing, throttling and placement of outflow pipes based on the available storage capacity and surface area within the lagoon system for the 1 in 30 year and the 1 in 100 year, 24 hour storm event.

To assess the storage capacity of the improved drainage system for various storm events, both discharge points (Discharge 1 and 2) have been assessed separately to reflect the different routes runoff will take through the quarry and treatment system.

During dry spells the quarry has no discharge; that is there is no base groundwater flow; however, even during "normal" rainfall events discharge takes place. Table 2 provides information on the storage available, outfall flow rates, surface areas available and a minimum particle size settlement that is achievable for "normal" rainfall events.

Table 3 provides information on the storage available, storage attenuation requirement, outfall flow rates, surface areas available and a minimum particle size settlement that is achievable for a 1 in 30 year 24 hour storm.

For Discharge 1 and 2, during the 1 in 30 year storm, the maximum instantaneous discharge flow rate has been calculated to be 3.14 and 3.2 l/s/ha, respectively. This flow rate provides enough storage within the lagoon system to provide attenuation of the storm event and also provides settling velocities to allow settlement of particles equal to or less than 6 microns.

For the fine particle fraction derived from the quarry runoff, Table 3 indicates that the capacity of the improved drainage system is adequate for an 80mg/l suspended solids discharge up to and including a 1 in 30 year 24 hour storm. However, Table 3 also shows that for the 1 in 30 year storm, the storage attenuation capacity within the system is approaching capacity for the throttled rates. This reflects the need to have a two tier discharge consent at the site, with a higher suspended solids limit and a storm discharge overflow route for the high magnitude, low frequency storm events greater than the 1 in 30 year storm.

Table 4 provides information on storm events up to the 1 in 100 year, 24 hour storm event, which includes both the throttled discharge (as shown in Table 3) and the storm discharge. The inclusion of the storm discharge in the Table 4 data results in the increase in maximum instantaneous flow rate.

Discharge location	Maximum instantaneous flow rate at discharge	Storage available	Surface area of lagoons for storm event	Theoretical settling velocity achievable	Minimum particle size settlement for the given velocity
Discharge 1	8.5 l/s (0.3 l/s/ha) for full pipe with no head	1900m^3	2700m^2	3.18 x 10^{-6}m/s	2 microns (Clay)
Discharge 2	4.2 l/s (0.22 l/s/ha) for full pipe with no head	1100m^3	1850m^2	2.39 x 10^{-6}m/s	2 microns (Clay)

Table 2. *Capacity of drainage and settlement lagoons for Discharges 1 and 2 for 'normal' rainfall events.*

Discharge location	Maximum instantaneous flow rate at discharge	Storage available	Storage attenuation requirement for the 1 in 30 year 24hr storm	Surface area of lagoons for storm event	Theoretical settling velocity achievable	Minimum particle size settlement for the given velocity
Discharge 1	84 l/s (3.14 l/s/ha) with 1m head	2400m^3	2395m^3	3000m^2	2.53 x 10^{-5}m/s	5 to 6 microns (Very fine silts)
Discharge 2	75 l/s (3.2 l/s/ha) with 0.55m head	2080m^3	2075m^3	2875m^2	2.37 x 10^{-5}m/s	4 to 5 microns (Very fine silts)

Table 3. *Capacity of drainage and settlement lagoons for Discharges 1 and 2 for a 1 in 30 year, 24 hour storm.*

Discharge location	Maximum instantaneous flow rate at discharge	Storage available	Storage attenuation requirement for the 1 in 100 year 24hr storm	Surface area of lagoons for storm event	Theoretical settling velocity achievable	Minimum particle size settlement for the given velocity
Discharge 1	248 l/s (9.27 l/s/ha)	2700m^3	2575m^3	3100m^2	6.86 x 10^{-5}m/s	10 microns (Fine silts)
Discharge 2	162 l/s (6.93 l/s/ha)	2850m^3	2460m^3	3150m^2	4.51 x 10^{-5}m/s	8 microns (Very fine silts to fine silts)

Table 4. *Capacity of drainage and settlement lagoons for Discharges 1 and 2 in a 100 year, 24 hour storm.*

Table 4 highlights that there is capacity in the lagoon system to attenuate storm events greater than the 1 in 30 year 24 hour event such as the 1 in 100 year storm. There is also surplus capacity to accommodate high magnitude, low frequency storm events greater than the 1 in 100 year event. However, to accommodate these events, flow rates out of the system need to increase and therefore settlement velocities within the system will increase. This, in turn, leads to a decrease in the ability to settle out very fine material. Table 4 above shows that to accommodate the 1 in 100 year storm the particle size settlement increases in relation to the 1 in 30 year 24 hour storm. Therefore, the suspended solids load within the discharge will also increase.

The maximum instantaneous flow rates for Discharges 1 and 2 are significantly under the pre-agreed GFR of 14 l/s/ha.

Summary

The drainage improvements to date are having a positive effect on the discharge at Criggion quarry. They are actively:

- Reducing and managing the production of silt to reduce the generation of fines.
- Managing uncontrolled runoff from the site and separating clean runoff from dirty runoff thereby reducing the volume of water that requires settlement.
- Increasing the amount of settlement and storage to reduce the suspended solids output and manage peak flows at the quarry discharge points.
- Utilising the limited space available in the optimum way from the top of the quarry to processing and product storage areas.

Discharge Consent

When this project started we were unaware of any two tiered discharge consents issued by the Environment Agency or its predecessors to quarries in England or Wales. In fact, when the concept was first discussed with the Environment Agency for this site, there was some resistance. The concept however has been in place in the sewage discharge environment, since discharge from combined sewers have been regulated.

The principles are straightforward: if the receiving water is at a high flow, with a high suspended solids load; what is the point of discharging water at a low rate and high quality at a far lower suspended solids load than the receiving water.

The fact that the Environment Agency considered the proposal and managed a unique application through the National Consenting system, is a testament to their pragmatism. It is important that this continues.

Applicability to other sites

Criggion presents unique challenges in a unique hydrological and quarry situation. This may have led to a unique solution. However, it can be argued that all quarries are unique in the combination of geological, geographic and operational constraints. The design of appropriate water management systems however have common themes and objectives:

- They should be well thought out.
- Designed quantitatively using appropriate and possibly modern assessment tools.
- Separate clean water from dirty.
- Drain haul roads.
- Consider high level attenuation through distributed small ponds.
- Consider velocity reduction techniques such as gabion walls and reeds.

The use of widespread two tier consents will be dependent on site specific situations. They certainly require careful assessment and design to achieve an appropriate tier level. The selection of the tier level must take account of the quality of the receiving waters at a range of flows from low flows to high flood flows. At high flows, the suspended solids load in the receiving water must be significantly higher than that from the treatment system. The colour of the discharge water and the receiving water may also have to be considered. The treatment system design, must include an appropriate step level balancing protection and a practical system that is essentially "self controlling". The nature of new Environmental Permits and MCERTS monitoring systems will result in a greater monitoring burden on the operator; but if the system and monitoring conditions are appropriate, then this may not be a bad thing.

References

Agricultural Development and Advisory Service (ADAS),1982. The design of field drainage pipe systems. ADAS Report 345. The Stationary Office, London.

Chow V.T, 1988. Applied Hydrology. McGraw Hill (pages 496-505).

Department for Environment, Food and Rural Affairs (DEFRA)/Environment Agency (EA), 2005. Revitalisation of the FSR/FEH rainfall runoff model. R&D Technical Report FD 1913/TR. Joint DEFRA/EA Flood and Coastal Erosion Risk Management R&D programme.

Department for Environment, Food and Rural Affairs (DEFRA)/Environment Agency (EA), 2007. Preliminary rainfall runoff management for developments. R&D Technical Report W5-074/A/TR/1 Revision D. www.defra.gov.uk/environment/flooding/documents/research/sc030219.pdf

Institute of Hydrology (IoH),1994. Flood estimation for small catchments. Report No. 124. Institute of Hydrology, Wallingford. www.ceh.ac.uk/products/publications/documents/IH124FLOODESTIMATIONSMALLCATCHMENTS.PDF

National Sustainable Urban Drainage Systems (SUDS) working group,(NSWG) 2004. Interim code of practice for sustainable drainage systems. www.environment-agency.gov.uk/static/documents/Business/icop_final_0704_872183.pdf

Pipe Flow Wizard v1.12, 2012. URL: www.pipeflow.co.uk.