Dorset Future Coast: Cliff Drainage Review and Options

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This technical note on the subject of 'cliff drainage review and options' has been prepared for the Dorset Future Coast project which includes project sites at Swanage North Cliffs and Charmouth. It is not intended to be used for the selection and design of drainage measures at any particular location, moreover, it provides a high level review of the geomorphological context and potential benefits of surface water and groundwater drainage to improve the stability of coastal cliffs and valley slopes.

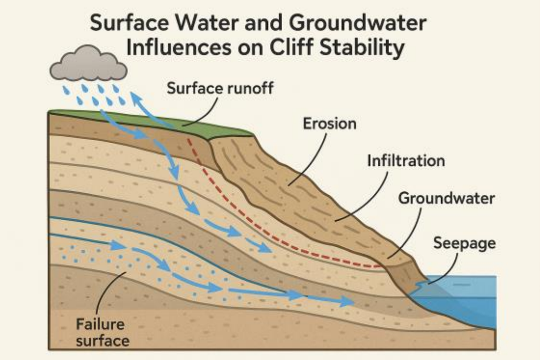
The scope and content of this technical note covers surface water and groundwater drainage under the following sub-headings:

- Surface water and groundwater influences on cliff stability
  - Principles of drainage for improving cliff stability
  - Limitations and uncertainties with cliff drainage
  - Hydrogeological ground investigations and monitoring
- Drainage methods:
  - Shallow drainage
  - Deep drainage and dewatering
- Ecological considerations
- Cliff hydrogeology and drainage at Charmouth and Swanage
  - Guidance for authorities and homeowners
  - Cliff hydrogeology and drainage opportunities
    - Charmouth
    - Swanage

1. Surface water and groundwater influences on cliff stability

There is generally a close relationship between surface water and groundwater systems. Surface water bodies such as rivers, streams, lakes and ponds, are often directly connected to the underlying groundwater conditions. For example, a stream or pond may coincide with the piezometric surface (also known as the water table), which is the level at which groundwater pressure equals atmospheric pressure. In such cases, the surface water feature essentially marks the point where groundwater reaches the surface.

This connection means that surface water can serve as a source of recharge for groundwater. Water from streams or ponds may infiltrate through permeable soils and rock layers, replenishing aquifers below. Conversely, groundwater can feed surface water bodies, contributing to their flow. This is commonly observed in springs, where groundwater naturally emerges at the surface due to hydrostatic pressure or geological formations. Groundwater aquifers may be confined under a semi-permeable or impermeable layer, such as clay or rock, resulting in artesian or sub-artesian pressures which can raise the groundwater above the top of the aquifer, and sometimes above ground surface, via natural pathways or drilling without the need for pumping.



In addition to surface water interactions, groundwater is also replenished through other mechanisms. One of the primary sources is the infiltration of precipitation, rainfall or snowmelt, that percolates through the soil and into the subsurface. Surface runoff, especially during heavy rain events, can also contribute to groundwater recharge if it flows over permeable ground or enters infiltration systems.

Urban development can influence groundwater recharge. For instance, septic tanks and soakaways (drainage systems designed to disperse wastewater into the ground) from residential or commercial properties can introduce water into the subsurface. While these systems can aid in recharge, they also pose potential risks of contamination if not properly managed.

Overall, the interaction between surface water and groundwater is complex and influenced by a range of natural and anthropogenic factors. Understanding this relationship is necessary for effective water resource management, environmental protection and infrastructure planning.

1.1 Principles of drainage for improving cliff stability

Groundwater pressure has a direct and significant influence on cliff/slope stability. Excess porewater pressure can exert a destabilising force on a potential landslide mass by reducing the effective normal stress (load) acting on the shear surface. This reduction in effective stress diminishes the frictional resistance, which is a key component of shear strength, thereby increasing the likelihood of cliff failure.

Secondary effects of excess groundwater pressure may include the emergence of groundwater at the cliff face or ground surface, leading to seepage, surface softening and gully erosion. These processes can further degrade the cliff/slope integrity and lead to progressive failure mechanisms.

The link between rainfall, groundwater levels and slope stability is well established, both empirically and theoretically. Rainfall infiltration can elevate groundwater pressures, particularly in permeable strata, triggering or accelerating ground movements and cliff failure. This understanding underpins the rationale for implementing surface water and groundwater drainage as a potential stabilisation measure.

As such, drainage interventions can be highly effective at improving cliff/slope stability for landslide-prone strata and locations. Potential benefits of surface water and groundwater drainage may include:

- Enhanced cliff stability: reduces porewater pressure and mitigates landslide risk.
- Infrastructure protection: safeguards roads, properties, public access and spaces.
- Economic value: supports tourism and development, ensuring and maintaining public safety.
- Climate resilience: proactive measure to mitigate increased rainfall and groundwater levels linked to climate change.

1.2 Limitations and uncertainties with cliff drainage

Cliff drainage design, installation and maintenance require careful consideration of the geological, hydrogeological and geotechnical factors, especially for complex cliff systems. While the fundamental principles of the effect of groundwater pressures on cliff stability are well understood and may be used as the basis of design of cliff stabilisation measures, in practice it may not be possible to predict the effectiveness of individual components of a drainage system. This is largely due to limitations and uncertainties in developing the hydrogeological ground model, for example knowing:

- The exact positions of geological formations and the boundaries between strata of different permeabilities.
- Inherent variations in material properties, including permeability, both vertically and laterally.
- The effects of discontinuities within a rock or soil mass, such as faults, joints and shear surfaces which can act as pathways for groundwater flow and significantly influence the effectiveness of drainage measures; the location and characteristics of individual discontinuities are usually unknown.
- The complexity of groundwater regimes consisting of stacked aquifers separated by formations of lower permeability, which may introduce effects of artesian pressures, or, conversely, underdrainage effects.
- The characteristics of cliff morphology which exacerbate uncertainties in local conditions, for example pre-failed masses within cliff systems will often show rapid lateral variation in material type and mass permeability characteristics depending upon the geology, materials and landslide history.
- The possible impacts of climate change on groundwater levels in the future.

For these reasons, drainage measures are usually designed and implemented as part of larger cliff stabilisation schemes in conjunction with other stabilisation methods which are less prone to design uncertainties. Use of the observational approach has advantages in that the design of drainage is adjusted through constant monitoring of its effects during construction. For example, if the baseline design does not drawdown groundwater pressures sufficiently to the required levels, then additional drains can be installed.

A further consideration with cliff drainage is the need for maintenance which is not always properly considered in the planning stages, nor implemented in practice. Proper maintenance of a drainage system throughout its operational life is essential to ensure the continued functioning of the system. A common issue in the design of cliff drainage systems is maintaining an outfall through the lower parts of the system, which may be subject to ground movements and be at risk of deformation and blockage.

1.3 Hydrogeological investigations and monitoring

Hydrogeological investigations and groundwater monitoring form a critical component of the planning and implementation of cliff drainage schemes. These investigations typically begin with a comprehensive ground investigation, which includes drilling boreholes, in-situ testing and instrumentation, geophysical surveys, sampling to understand subsurface conditions such as soil and rock permeability, groundwater levels and flow paths.

Following this, the development of a preliminary hydrogeological model is crucial. This model synthesises data from the ground investigation to conceptualise the groundwater regime, including recharge zones, flow directions, aquifer properties and potential seepage zones that may contribute to cliff instability. The model serves as a decision-support tool for designing effective cliff drainage systems, such as horizontal drains, deep wells or surface water drainage channels/pipes.

Drainage trials, such as pilot installations of drains or pumping tests, are then conducted to validate the model and assess the feasibility and performance of proposed drainage solutions under real conditions. These trials help refine the design by providing empirical data on flow rates, drawdown effects, and the interaction between groundwater and cliff instability/movement.

To ensure the long-term success of cliff drainage measures, monitoring is essential. This includes both short-term monitoring during and immediately after investigation and construction to verify installation quality and initial performance, and long-term monitoring to measure and evaluate the effectiveness of the drainage system. Monitoring typically involves instrumentation such as weather stations, downhole piezometers, inclinometers and flow meters, integrated with remote sensing or automated data acquisition systems.

Monitoring is crucial when drainage is the primary stabilisation method, as its failure or underperformance could lead to renewed cliff instability. Monitoring data can inform maintenance needs, trigger early warnings and guide future interventions.

2. Drainage methods

Methods of surface water and groundwater drainage can be approached in a number of different ways including the provision of cut-off drains to intercept water before it enters a cliff or landslide area with the aim of achieving a reduction in groundwater pressures, as well as the drainage and disposal of surface water run-off and groundwater out of harm's way. The ability to have an impact on groundwater levels will depend on the extent, depth and mechanisms of cliff instability as well as the nature of the geology and soils and their degree of permeability.

Cliff drainage systems can be broadly categorised into two types:

Shallow drains – typically comprising open ditches or gravel-filled trenches. These are designed to intercept and divert surface water runoff and reduce pore pressures in shallow groundwater systems, generally within a few metres of the ground surface.

Deep drains – encompassing a variety of systems, which target deeper groundwater regimes. Their primary function is to lower pore pressures acting on deep-seated landslide shear surfaces, often located several metres below ground level.

In areas where the principal form of drainage is surface water, shallower drainage measures are likely to be most suitable whilst deep drainage systems which may include cut-off drains, wells and adits, are more appropriate for deeper-seated complex cliffs and landslides. Consideration must also be given to the economic benefit of the proposed drainage scheme which will be related to the level of risk to development and public safety from cliff instability.

This section gives a brief overview of some of the principal types of drainage methods which might be considered to improve the stability of cliffs and slopes.

2.1 Shallow drainage

2.1.1 Surface water drainage

Local drainage to control surface water run-off typically takes the form of shallow ditches either left open or backfilled with gravel to the ground surface. This has the effect of reducing infiltration of rainwater above and within cliffs and may form part of an overall drainage scheme. However, while having a positive effect on the inputs to the groundwater regime, it would not be sufficient on its own to provide a reduction in groundwater pressures at depth which could be relied upon for effective stabilisation.

2.1.2 Drainage of ponds

Ponds often represent the surface expression of a piezometric surface, and hence it may be possible to directly reduce water pressures acting on cliffs and pre-existing shear surfaces simply by installing drainage to lower the level of the water in the pond. However, the amount of drawdown that can be achieved is likely to be small compared to the overall head of water acting on the shear surface. Hence, whilst having a direct positive effect on groundwater pressures at depth as part of a scheme, it would not be sufficient on its own to provide a reduction in groundwater pressures which could be relied upon for stabilisation.

2.1.3 Trench drains

Trench drains are channels cut into the ground which are then backfilled with permeable material such as gravel, and which may have an impermeable lining on one face and/or a permeable geotextile wrap to prevent ingress of fines into the drainage system. They are limited in depth to the digging reach of the type of excavator which can access the site, typically up to 4 m. If sufficiently closely spaced, they may be effective for drawing down groundwater in shallow regimes for cliffs and landslide systems where the shear surface is at a relatively shallow depth, or as a cut-off where the ground model indicates that groundwater may be flowing into the cliffs/landslide system through a shallow aquifer underlain by a less permeable stratum a few meters below ground level. Trench drains may be designed to penetrate below the cliffs and landslide shear surface to provide additional strength (shear keys) due to the fictional properties of the infill material. Trench drains can play a role for local stabilisation of cliffs in critical areas but will not address the stability of the large-scale complex cliff / deep-seated landslide systems.

2.2 Deep drainage and dewatering

2.2.1 General

Well drains refer to the installation of deep wells which are typically vertical boreholes provided with a permeable liner which supports the sides of the hole, whilst allowing water to enter the well. The wells reduce groundwater pressure by removing water from the system through a variety of methods. Each well will have a zone of influence around it where groundwater is drawn down around the well in a cone of depression, the radius and characteristics of which will depend upon the permeability of the surrounding material and the nature and distribution of discontinuities such as joints. Wells are designed to drawdown water pressures by a specific amount to ensure an adequate factor of safety and improvement of cliff/slope stability. This is often the equivalent of ensuring that winter groundwater levels are kept at or below normal summer groundwater levels, so that the triggering of cliff instability which typically occurs during the winter or early spring does not occur. Due to the inherent variability in ground conditions, and mass permeability in particular, within cliff systems, the effectiveness of each well can only be predicted in general terms on the basis of ground investigation and pumping tests, and actual performance needs to be confirmed through the monitoring of groundwater pressures around the well in a series of separate observation wells. As each well has a limited radius of influence and in order for them to be effective as a stabilisation measure, wells need to be installed in groups, often closely spaced and in lines with each well being less than 10 m away from its neighbours.

2.2.2 Pumped wells

In pumped wells groundwater lowering is achieved with pumps that remove water to the surface from each well. Electro-pneumatic pumps are generally favoured as they have simple parts which are easily maintained. These pumps operate using compressed air from a compressor house that flows through an airline to the pump when required. Pumped wells have been used successfully at Castlehaven Undercliff, Isle of Wight, where drawdowns of 5 to 10 m below surface level have been achieved at the position of the wells, to about 20 m below ground level. Pumped wells are a potentially feasible option for a cliff drainage system, allowing considerable reduction of groundwater pressures at depth, and having a proven track record at Castlehaven and other UK sites e.g. Fairlight, East Sussex.

2.2.3 Siphon drainage

Siphon drains work on the same principle as pumped wells except that the water is removed not by pumps but by gravity along siphon pipes which are kept primed by an automatic system located at the downstream outlet of each siphon pipe. The system requires an accessible and stable location for siphon outlets at a level lower than the intended design groundwater level. The system is limited to what drawdowns can be achieved compared with a pumped system (with the practical limit of drawdown of a siphon drain being around 8 m). The required drawdown of groundwater is likely to be relatively large in order to provide an adequate factor of safety and improvement in cliff stability, and there is also the potential difficulty of providing suitable sites for siphon outlets at a lower level upon or below the cliffs. Hence it is considered that siphon drainage has significant disadvantages compared to pumped wells.

2.2.4 Relief wells

Relief wells are used in locations where artesian water pressure drives landslide movements. Wells are drilled into a confined aquifer through the overlying aquiclude, and groundwater is allowed to rise to the surface under artesian head thereby reducing the pressure on the cliff and landslide shear surface and increasing stability, requiring neither pumps or siphons. This is a potentially cost effective technique in those areas where artesian heads are known to exist, needing less equipment and maintenance than either siphon drains or pumped wells.

2.2.5 Drilled drains

2.2.5.1 Sub-horizontal drilled drains

Sub-horizontal drilled drains are constructed by drilling a hole at a shallow angle up into the cliff, using a conventional drilling rig, and installing slotted pipe. Groundwater pressures are reduced to zero at the position of the drain, which discharges water by gravity down the pipe. Like wells, the effectiveness and zone of drawdown of sub-horizontal drilled drains is very much dependent upon local geological conditions, and they generally need to be installed in groups, for example in fan arrays or individually at relatively close spacing of less than 10 m. There is a limit to the practical length of installation which may be achieved using conventional equipment, typically around 50 m, due to the drill string drooping under its own weight eventually leading to backfalls in the drain if extended too far. Sub-horizontal drill drains are most effective where they are drilled into water bearing strata or along shear surfaces where there is easy access to the outcrop where a drilling rig may be set up, and where a stable outfall location can be built and maintained.

2.2.5.2 Directional drilling

Directional drilling is a more sophisticated and costly method than sub-horizontal drilling but with an advantage that the drilling direction may be controlled and steered to a precise course. This method is typically used for installing pipes and services under major obstacles such as roads and rivers and for constructing sea outfalls. The method could potentially be adapted to form drains, however the problem of maintaining stable outfalls in the lower sections of cliffs remains.

3. Ecological considerations

Cliff environments in the UK are ecologically sensitive and often host rare or protected species. In most cases, cliff drainage will have negligible impact but in certain circumstances could impact ecology and habitat due to altering the natural surface drainage and groundwater flow paths and introducing long-term changes to the natural cliff hydrology. Any cliff drainage proposals should, therefore, comply with the following legal, regulatory and other considerations through the feasibility, planning and design stages:

Habitat Integrity:

- Maritime cliff and slope habitats are designated under UK conservation frameworks.
- Drainage works can disturb soil moisture regimes, affecting plant communities and dependent fauna.

Biodiversity Net Gain (BNG)

- UK planning law requires a minimum 10% biodiversity net gain for new developments.
- Drainage schemes can contribute through:
    - Vegetated swales and ditches.
    - Wetland creation.
    - Habitat restoration alongside engineering works.

Design and Mitigation

- Apply the mitigation hierarchy: avoid, minimize, restore, offset.
- Maintain ecological connectivity across cliff systems.
- Include long-term monitoring to assess ecological impacts and adapt management strategies.

Environmental Impact Assessment (EIA)

Cliff drainage projects may require an EIA under the Town and Country Planning (Environmental Impact Assessment) Regulations 2017, particularly if they:

- Affect designated habitats or species.
- Are located in sensitive coastal zones.
- Involve significant earthworks or hydrological changes.

4. Cliff hydrogeology and drainage at Charmouth and Swanage

There are two parts to an effective strategy to control surface water and groundwater drainage for cliffs at Charmouth and Swanage.

1. The first part would aim to prevent surcharging of the natural surface and groundwater sources from urban development and drainage networks, specifically to prevent, identify and repair uncontrolled leakages when they happen and replace soakaway discharges with sealed disposal systems. This initiative would involve collaboration of Dorset Council and the relevant authorities, water supply and drainage services and land/property owners. Further guidance is provided below.
2. The second part would consider the relative merits of shallow and deep drainage measures to improve the stability of the cliffs at Charmouth and Swanage. Opportunities for drainage measures is presented below based on an understanding of the local hydrogeology of the coastal cliffs and valley slopes.

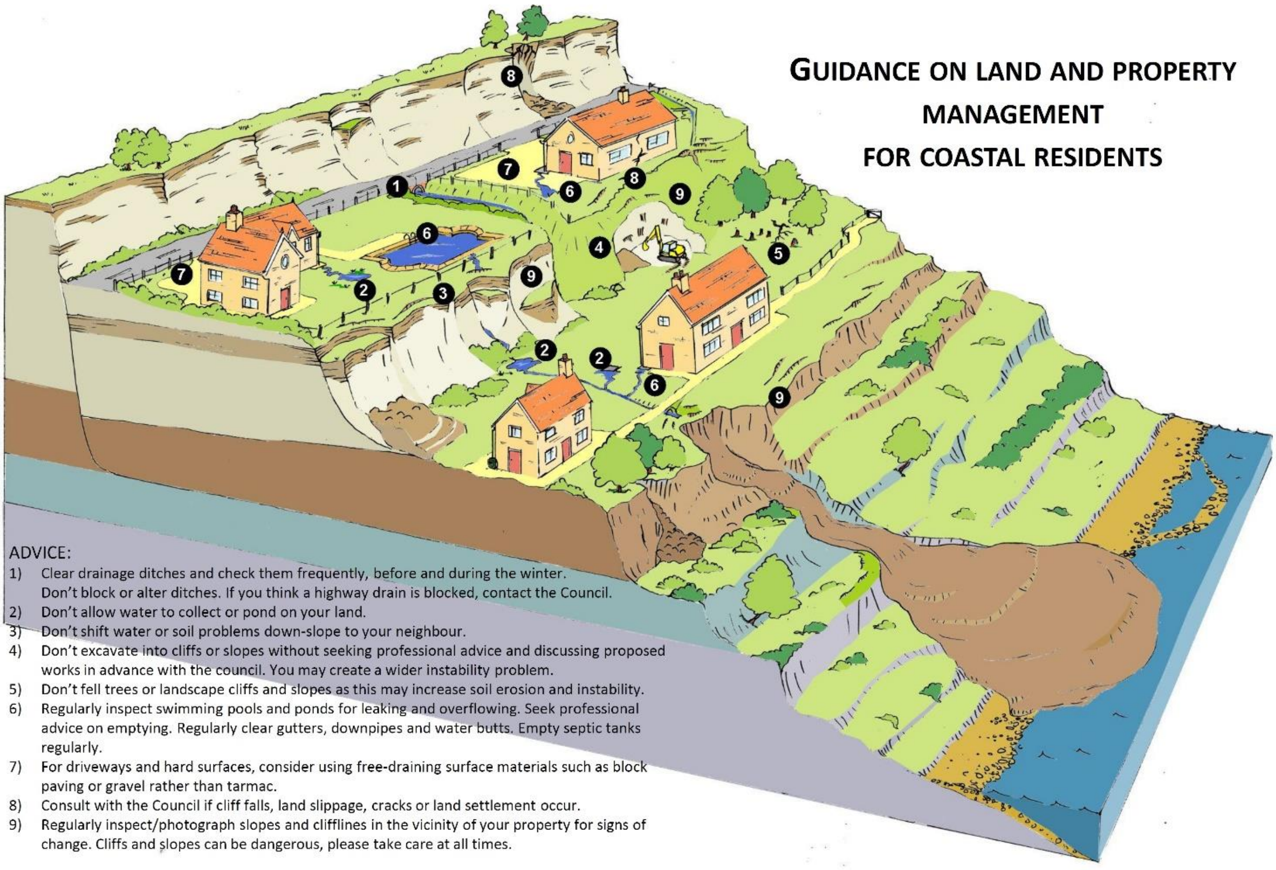
4.1 Guidance for authorities and homeowners

Guidance for land and property management for coastal residents is shown in the figure below.

Whilst the efforts of individual property owners may only have a small local influence on cliff instability in their community, the cumulative effect by many homeowners can have a significant benefit. Activities such as vegetation removal, lack of maintenance or inattention to leaking pipes, can all adversely affect cliff stability. Local residents can play an important role in identifying and reporting potential issues such as water leakages. Before the onset of the autumn/winter period property drainage systems such as gutters and downpipes should be checked for leakage and highway drainage systems and ditches should be cleared.

Use of soakaway drains for highways and properties have often been linked to ground instability problems; this applies to older assets and properties as new build regulations require connections to mains drainage systems. Opportunities may exist to replace soakaways with sealed drainage pipes disposing to nearby mains drainage which is to be encouraged. Residents, working individually or in groups, for example by area or by road, can ensure that issues such as maintenance of highway drains and drainage systems are being addressed by the local authority or the responsible water utility company. For multiple occupancy properties there is a collective responsibility for all inhabitants to contribute towards the management of the building and its grounds. It is sometimes more difficult for tenants, particularly in large buildings that have been divided, to ensure that a coordinated approach is taken to address structural maintenance and property drainage issues; this may be addressed through a residents' group or management committee. Lack of maintenance could make the property and buildings more susceptible to cliff instability so regular inspection and maintenance are particularly important and effective at preventing problems before they become more serious.

Many coastal slope and cliff problems can be linked to high groundwater levels, which in combination with other factors such as coastal erosion or human activity can promote land instability. Measures which control these factors will assist in reducing the likelihood of future movements, but they will not eliminate the risk. Rainfall and groundwater can act in a number of ways to promote slope failure, first as 'preparatory factors' which work to make the slope increasingly susceptible to failure without actually initiating it (i.e. causing the slope to move from a stable state to a marginally stable state, eventually resulting in a low Factor of Safety). Second, as triggering factors which actually initiate movement, i.e. shift the slope from a marginally stable state to an actively unstable state. A common scenario is for a transient event, for example, an intense storm, to trigger landslide activity after there has been a gradual decline in stability (over a prolonged wet period). Both rainfall and groundwater can therefore have a long-term and short-term influence on coastal slope stability.



Research carried out at Ventnor Undercliff, Isle of Wight, has demonstrated a clear relationship between winter rainfall and groundwater levels, and the coincidence of cliff instability and excess groundwater pressures (Moore et al, 2007; 2010). Improving ground conditions through the control of water can therefore play an important role in minimising the impacts of ground movement in developed areas.

4.2 Cliff hydrogeology and drainage opportunities

A review of the hydrogeology and developed areas and cliff at Charmouth and Swanage can be used to assess the relative merits of the two-part drainage strategy presented above. At both sites where urban development encroaches the cliffs, control of surface water drainage is important to prevent surcharging of the natural groundwater table. Implementation of the guidance presented above will ensure benefits in achieving effective surface water disposal to sealed systems and prevention of water leaks and thereby ensure the stability of cliffs.

In specific locations where significant surface water and groundwater sources have been identified, resulting in local cliff failure and instability, there may be an opportunity to consider shallow or deep drainage to mitigate the problem either as a primary measure or as part of a larger stabilisation scheme e.g. Pines Hotel, Swanage. It is noted, however, any cliff drainage proposals and designs at Charmouth and Swanage will need to integrate ecological expertise early in project planning, be informed by appropriate surveys and investigations to understand the site-specific hydrogeology and habitat interactions, consider design for adaptability, allowing for future climate and ecological changes. Furthermore, proposals will need to engage relevant stakeholders, including conservation bodies and local communities, and comply with laws and regulations.

4.2.1 Charmouth

The hydro-geomorphological features at Charmouth controlling surface water and groundwater drainage can be separated into **Coastal Cliffs, Valley-side Slopes** and Plateau (Figure 4-1). Whilst the plateau forms the upper part of the local natural drainage catchments it has no direct connection with the frontage and urban area at Charmouth so is not considered further here.

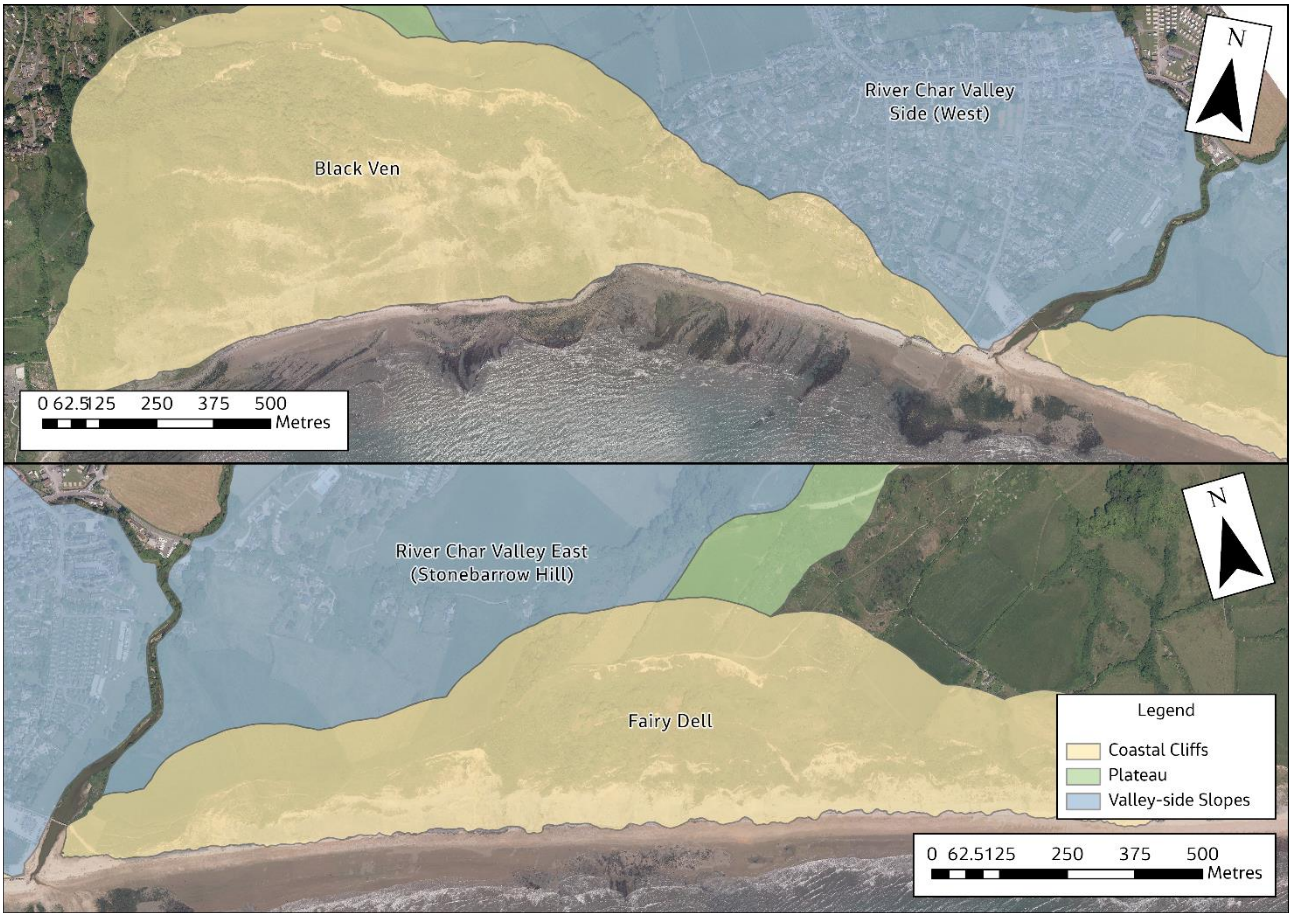


Figure 4-1: Map showing hydro-geomorphological features at Charmouth. Note that the Coastal Cliffs include the projected "potential zone of future instability" from NCERM2.

4.2.1.1 Coastal cliffs

The coastal cliffs are natural systems characterised by strongly interbedded strata of sandstone, clays and limestones. The upper sequence comprising Cretaceous Upper Greensand sandstones is porous and free draining above the largely impermeable clays of the Lower Jurassic Charmouth Mudrocks. The interface between these units forms an impermeable barrier to vertical flow directing groundwater to drain sub-horizontally down-dip (2-3° Southeast) to the lower cliffs and valley sides at Charmouth; the bedding is locally folded and faulted which influences groundwater flow paths and drainage. The source, pathways and discharge of groundwater is a primary control on the occurrence of the deep-seated landslides[1] at Stonebarrow and Black Ven.

Given the scale and naturalness of the complex coastal cliffs coupled with the absence of any development at risk in the immediate future, there is no requirement to consider drainage of the coastal cliffs with perhaps one exception, Higher Sea Lane.

[1] Landslides comprise multiple mechanisms and materials including rotational and translational slides, flows and rockfalls

4.2.1.1.1 Higher Sea Lane

Site investigations into the Higher Sea Lane landslide at Charmouth carried out by Bruce Denness (1975) and Robert J. Allison (2020) highlighted the role of groundwater as a principal cause of the rapid erosion and landsliding that threatened a private housing estate in the late 1960s. The landslide was linked to a relict mudflow, with instability exacerbated by groundwater from the Upper Greensand. The investigations aimed to propose remedial works and assess the effectiveness of shallow geophysical and geotechnical methods not commonly used in landslide studies.

The findings emphasised the role of stratigraphy and groundwater in triggering landslides, and the recurrence of mass movements due to the geological configuration. The drainage pattern was found to be extremely complex with saturated superficial sandy soils and partially saturated layers of clay breccia overlying in situ Lower Lias mudrocks. This is of significance to remedial drainage works design as the saturated areas are the most unstable and were found to coincide with rapid cliff erosion. Denness (1975) proposed two drainage solutions: shallow trench drains discharging to sealed mains drainage inland and a line of interception boreholes acting as vertical drains through the Lias to the sea.

As a result of these investigations, the design and installation of a drainage scheme to intercept and redirect groundwater away from the slope using trench drains was implemented. This drainage scheme was specifically aimed at reducing pore water pressures and improving the slope stability locally at Higher Sea Lane. The scheme was part of a broader effort to protect nearby residential properties and infrastructure from further movement. While the drainage scheme did not dominate the coastal geomorphology like the larger landslide complexes at Black Ven or Stonebarrow Hill, it was a significant local intervention to manage slope instability in the village of Charmouth.

4.2.1.2 Valley-side slopes

The valley-side slopes are characterised by pre-existing landslides of some considerable age (e.g. Pleistocene or early Quaternary period). They are marginally stable but are likely to be sensitive to reactivation due to changes in slope stress state such as local slope cutting and filling (unloading and loading) and reduction in material strength due to excess groundwater pressures and weathering. The Higher Sea Land landslide and more recent spreading failure at Evan's Cliff provide compelling examples of the reactivation of relict valley-side landslides due to cliff recession and groundwater. Consequently, it is advisable to control development activities through local planning and building regulations and adoption of good practice guidance for land and property owners (see above).

The guidance to land and property owners is particularly relevant in this regard for development. Planning and Building Control have responsibility to ensure proposals for new development are appropriate and sustainable. Control of surface water drainage will have significant benefit in ensuring the stability of the valley side slopes through early identification and repairs of leakages and replacement of soakaway drains.

In view of the findings of the ground investigation at Higher Sea Lane, which proved the depth of the relict mudslides was about 3.5m, the benefit of deep drainage is less clear and may only be considered for larger developments involving deep foundations. Permanent dewatering of such excavations will improve slope stability but would need to be preceded by appropriate ground investigations and design of drainage solutions.

In summary, drainage solutions of the valley-side slopes at Charmouth may include:

- Control of surface water from urban development through planning and building controls
- Connections to sealed mains drainage where possible (e.g. soakaways)
- Dewatering of deep foundations (new development)
- Drainage of ponds and flushes to stream courses

- Trench drains e.g. Higher Sea Lane

4.2.2 Swanage

The hydro-geomorphological features at North Cliffs that control surface water and groundwater drainage can be separated into sub-vertical **Coastal Cliffs** and local valley features known as **Chines** (Figure 4-2). These features can be observed along the defended section from Shore Road to Ballard Estate and the undefended section from Shep's Hollow to Ballard Down Cliffs.

Figure 4-2. Map showing hydro-geomorphological features at Swanage North Cliffs.

4.2.2.1 Coastal cliffs

North Cliffs are characterised by Wealden interbedded strata of porous and impervious rocks that create a complex hydrogeological regime of perched water bodies (aquifers). There is potential for confined aquifers to develop in porous sandstones between relatively impermeable clay layers with discontinuous and connected drainage pathways to the cliffs where local seepages and springs can be observed. The coastal cliffs are connected to a natural surface water catchment and groundwater drainage system that extends north to Ballard Down. This natural system is likely to be locally surcharged by surface water runoff and drainage from urban development of the cliffs between Shore Road and Ballard Estate.

The guidance to land and property owners is particularly relevant in this regard for existing development. Planning and Building Control have responsibility to ensure proposals for new development are appropriate and sustainable. Control of surface water drainage will have significant benefit in ensuring the stability of the cliffs through early identification and repairs of leakages and replacement of soakaway drains.

Ground investigations and drilled drains installed up to 12m into the cliff at the Pines Hotel in 2016 proved that some were 'gushers' whilst others produce no groundwater and have remained dry. Since the works were completed, several of the drilled drains have continued to 'bleed' groundwater at a relatively constant rate i.e. no obvious seasonal response to rainfall. From this explanation and evidence, it is likely that hydrogeological investigations and deep drainage will only be partially successful given the high lateral and vertical variability in groundwater bearing strata and drainage pathways.

Realistically, drainage of the cliffs utilising deep drilled drains should only be considered in locations where there is evidence of groundwater issues from the cliffs associated with potential instability and risk to assets.

4.2.2.2 Chines

There are a number of local chines or valleys (e.g. Burlington Chine) which drain to the shoreline. A chine is a local name given to a steep-sided valley cut into soft sandstones and clays by a stream over thousands of years. They are largely relict features but still serve as small drainage catchments with misfit, buried and or ephemeral streams (e.g. winter flows). Coastal erosion and cliff recession has cut and removed the lower section of the chines which are now left as 'hanging-valleys'. Along the freely eroding cliffline north of Shep's Hollow, residual stream flow from the chines can be seen cascading over the sea cliff as water falls. Along the defended section of North Cliffs, there are two chines which have been developed for access and private development (gardens). It is not known whether the drainage from these chines is discharged by formal pipes and outfalls beneath the promenade and beach or whether the groundwater and streams back-up behind the promenade and structures that have been built. Evidence of seepage behind the promenade and wall at the Grand Hotel suggest the latter may be the case. Build up of groundwater pressures could well be a factor in the evident ground movement and damage to these assets.

In summary, drainage solutions at North Cliffs may include:

- Control of surface water from urban development through planning and building controls
- Connections to sealed mains drainage where possible (e.g. soakaways)
- Drilled drains e.g. Pines Hotel

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