Modelling flow, erosion and long term evolution of incising channels: managing hydrology and geomorphology for ecology

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Abstract The Isle of Wight Chines are deep, canyon-like features, caused by small streams incising through soft cliffs as they flow to the sea. The actively eroding Chines provide unique habitats of significant ecological value. The long term geomorphological evolution of the features is of importance when making managerial decisions and implementing policies. A conceptual model of Chine evolution is being formulated in conjunction with ecological and invertebrate surveys, in an attempt to predict the various morphological and ecological stages of Chine development. In a Habitats Directive review of abstraction consents by the UK Environment Agency, the effects of varying abstraction rates were assessed. Licensed abstractions were predicted to reduce natural erosion by up to 90%. The details of this assessment and the long term evolution model of the Chines are presented within the framework of managing the Chines for the sustainability of ecology.

Key words Chines; conceptual; ecology; jet testing; management; modelling

INTRODUCTION

Incising channels are features of disturbed landscapes, which are often associated with ecological degradation (Brookes, 1988). A series of incising channels which cut deep (up to 45 m) canyon-like features through the soft cliffs on the south coast of the Isle of Wight, UK, are, however, of significant ecological value. These channels, known locally as “Chines”, sustain a range of diverse habitats and species because of the ongoing incision, and associated geomorphological processes. For this reason the Chines form a key component of the “Vegetated sea cliffs of the Atlantic and Baltic coasts” habitat of the South Wight Maritime Special Area of Conservation (SAC), as designated under the EU Birds and Habitats Directive. Complex links exist between hydrology, geomorphology and ecology within the Chines and the research presented below has highlighted the fact that they are highly sensitive features. Managerial decisions and policy implementation can thus have a significant and far reaching effect on both geomorphological development and biodiversity and must therefore be based on a well informed understanding of the system.

A number of pressures are being exerted on this sensitive environment with potentially damaging effects. Many of the Chines are used as natural access points to recreational beaches and many are found within farmland. On the shorter temporal scale, one of the key problems facing the future development of the Chines is the abstraction of water. In a recent Habitats Directive review of abstraction consents by
the Environment Agency, the effects on Chine erosion of varying abstractions were assessed, the results of which are presented and discussed below. Such research adequately addressed the abstraction issues although it became evident that only through an in-depth understanding of the longer term development and evolution of the features could future management decisions be made. For example, the development of the Chines could be threatened by a series of fixed grade controls, imposed where a road crosses each of the streams. An understanding of individual Chine development can be used to assess the potential impact of such artificial controls. In order to deliver this understanding, a conceptual model of Chine evolution has been developed which is also presented below. Alongside this, detailed ecological and invertebrate surveys are being undertaken which, when linked to the model, will provide an understanding of the relationship between the geomorphology and biodiversity.

STUDY SITE

The Chines are primarily found along the southwest coast of the Isle of Wight (Fig.1) where the shoreline morphology consists of soft cliffs varying in height from 15-100 m. The Chines consist of streams that have cut down through the soft cliffs to varying depths. The Chines drain catchments with areas ranging from 11.7 km² for Grange Chine to 0.1 km² at Ladder Chine.

Ecological significance

The UK’s maritime soft rock cliffs support rich invertebrate assemblages and act as a refuge for rare insect species. A recent review by Howe (2002) lists 29 species of

![Fig. 1 Location of the Isle of Wight and the Chines.](image)
invertebrate found only on soft rock cliffs, of which, 23 are Red Data Book species. They include rare tiger beetles, ground beetles, weevils, craneflies and, in particular, solitary bees and wasps. Many of these species are restricted to the Isle of Wight coast, including the Glanville Fritillary butterfly *Melitaea cinxia*, and the digger wasp *Psen atratinus*. There are a range of reasons why maritime soft cliffs should be of such ecological interest. Soft cliffs offer a historic continuity of pioneer ecological conditions, complex mosaics of microhabitats that alone and in combination provide ideal conditions for a range of insects and other invertebrates. Bare ground is of key importance to invertebrates on soft cliffs and other habitats (Key, 2000). Also significant are hydrological features such as freshwater seepages, and physical aspects such as temperature. The reliance of diverse invertebrate communities on bare ground habitats and pioneer vegetation communities, features of disturbed environments, means that the ecological interest of the Chines is intrinsically linked to their geomorphological functioning.

**HYDROLOGICAL AND GEOMORPHOLOGICAL MODELLING**

As one of the competent authorities under the Habitats Regulations, the Environment Agency must assess the possible effects of the various permissions on, or potentially affecting, a *Natura 2000* site. In this context, this requires that all licensed water abstractions are reviewed in terms of their potential impact on the Chines. These abstractions are used for a variety of uses, but principally for intensive irrigation of potatoes: an important crop of high economic value to the area. Because the geomorphology of the Chines is essential to their ecological importance, the study focused on the relationships between abstractions, flow and erosion. If the flow in the Chines is being reduced by abstractions such that its potential to cause erosion is inhibited, then the abstractions may be affecting the habitats and ecology of the Chines as described above.

Due to the physical and chemical composition of cohesive sediments such as those found in the Chines, assessing their erosion resistance is complex. Numerous studies, employing a variety of techniques, have concluded that there are many properties that affect erosion resistance (Grissinger, 1982). Hanson & Simon (2001) report the successful application of “*in situ* submerged jet testing apparatus to measure the erosion resistance of several streambeds in the loess areas of the midwestern USA”.

This test gives consistent results, and can be used to parameterise the following standard equation of erosion rate ($\varepsilon$, m s$^{-1}$):

$$\varepsilon = k_d (\tau_e - \tau_c)$$

(1)

where $k_d$ is the erodibility coefficient (m$^3$ / N$^{-1}$ s$^{-1}$), $\tau_c$ is the critical shear stress (Pa) and $\tau_e$ is the effective shear stress (Pa). Specifically, the jet testing is used to determine $\tau_e$ and $k_d$ from jet-test scour results (Hanson & Cook, 1997).

*In situ* jet test apparatus (Fig. 2) was used to measure the erosion threshold of the sediment of those Chines with abstractions in their catchments: Churchill, Brook, Grange and Shepherd’s (in two locations, Shepherd’s 1 and 2). The base of the apparatus was driven into the substrate, such that the submergence tank at the base of the apparatus was sealed. This tank, together with the head tank were then filled with
water by a pump. At a constant pressure, the jet nozzle was opened, allowing a fine jet of water to impinge on the sediment. An integral point gauge is used to measure the scour caused by the jet, at regular time intervals. Further details of the method are provided by Hanson & Simon (2001).

A simple, semi-distributed rainfall–runoff model was calibrated using gauged flow data. This model was used to generate flow sequences, which were used as inputs to the erosional model. Total erosion (incision) was calculated under two scenarios: natural (no abstractions), and abstracted (with all abstractions being taken at the fully licensed quantities). This allowed the relationships between flow, abstraction and erosion to be analysed as shown in Figs 3 and 4. The ratio between the natural and abstracted total erosion was then used to determine whether any abstraction licenses have potential to inhibit erosion (Fig. 5), thus affecting the geomorphological and ecological development of the Chine (Fig 4).

As a result of this study, informed management decisions relating to abstractions can be made. However, it is clear that there are a variety of other management
decisions that will need to be addressed in the medium to long term. These will require a more thorough understanding of the development, evolution and functioning of the Chines.

**AN EMPIRICAL–CONCEPTUAL MODEL OF CHINE EVOLUTION**

Possible future management decisions that may affect the Chines are likely to concern the geomorphological interactions between the rapid coastal retreat (up to 2 m a\(^{-1}\)) of the soft cliffs (May & Hansom, 2003), the headward retreat of the Chines, and the flow
discharge within the features. These are effectively the dynamic development controls on the features. The effects of decreases in discharge on rates of down-cutting have already been discussed. This section attempts to deal with the longer term interactions between these drivers in the context of evolutionary stages. In order to make informed decisions a detailed understanding of the formation and evolution of the Chines needs to be presented which can then be used as a predictive tool. A conceptual model of Chine formation and evolution has been developed and is presented below using the realistic management scenario example of the effect of a road grade control structure on the development of a Chine.

Development of a theory: thresholds of change within the Chines

The key driver of Chine development is shoreline retreat (Flint, 1982) and hence their stability depends upon the balance between relative rates of cliff retreat and knickpoint recession. It is proposed that geomorphic thresholds (Schumm, 1973) exist within the Chines beyond which the system state changes significantly. These thresholds are manifested in a critical cliff recession rate, \( CR_c \), and a critical knickpoint recession rate, \( KR_c \). Whilst cliff retreat rates are well documented on the Isle of Wight, knickpoint recession rates are not. They can be calculated using the commonly used relationship (Leopold et al. 1964):

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KR = A.S^{0.5}
\]

Where \( A \) is area and \( S \) is channel slope. The exponent of 0.5 is adopted from Manning’s equation. If the knickpoint recession rate is greater than the cliff recession rate then the Chine will be in a state of stability or growth, if it is lower then the Chine will be in decay.

Methodology

Based upon the work of Schumm et al. (1984) and Simon & Hupp (1986) who looked at evolutionary stages in incised channels, a space-time substitution method (Schumm, 1991) was employed to identify a sequence of evolutionary stages within the Chines. Cross sections and long profiles of a number of Chines were surveyed in order to allow the development of a generic model. The drainage areas were calculated using a GIS and combined with the slope measurements to produce knickpoint recession rates. Detailed plant, habitat and invertebrate surveys were undertaken for a selection of Chines by Simon Colenutt, an experienced ecologist working on behalf of Buglife and the Environment Agency.

Development of a new Channel Evolution Model (CEM)

Using the observations and data surveyed from the Chines a new CEM was developed (Fig. 6). In contrast to existing incised CEMs, which cite the lowering of a base level at a fixed point (usually the downstream limit of the channel) as the cause of incision,
the base level of the Chines is the sea, which is dynamic and spatially mobile. The stability of the Chines as a function of knickpoint and cliff recession rates (Fig. 7) can be plotted and used in conjunction with the CEM to assess the sensitivity of a given Chine and possible future evolutionary developments. Using the plant and invertebrate survey results it is hoped that the successional development of the ecology can be retro-fitted onto the model so that the links between geomorphological evolution stage, plant and invertebrate species, and micro-habitats can be mapped out.

Application of the model to a management scenario

The empirical-conceptual model outlined above can be used in number of ways to aid important managerial decisions. The A3055 military road crosses many of the Chines at their inland extent and on some of the larger features there are grade control structures. Upstream of these structures the Chines represent the stage I, pre incision

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Fig. 6 A channel evolution model (CEM) for the incised coastal channels on the Isle of Wight, UK.
channel morphology on Fig. 6 and the structures effectively impede the development of the Chine head-cut inland, meaning that the Chine cannot progress beyond stage I, at or inland from that location. The Chine will therefore fall into decay (stages VI and VII on Fig. 6 and points 1 and 2 on Fig. 7) before ultimately being destroyed by cliff recession. As the Chine ceases to be geomorphologically dynamic and decays, so too do the habitats within them.

As the road will be threatened by the same cliff recession it is likely that re-routing schemes will be developed and this will present a considerable opportunity to use the model to help inform the developers within the context of managing the important ecological habitats for optimal development. The model can also be used in a predictive manner to notify engineers of potential areas of instability due to future Chine development.

The next stage of this ongoing work is to develop a numerical landscape evolution model (LEM), parameterized by historical and contemporary development in order to predict future morphological development under various land use and climate change scenarios.

CONCLUSIONS

The research and results outlined above represent initial progress in understanding the Chines of the Isle of Wight, which have previously received very little research attention. The hydrological and geomorphological modelling has allowed specific questions regarding existing and new abstractions to be made with an understanding of the implications for the functioning of the Chines. The Chines will require future management decisions to be made, possibly on a larger spatial and temporal scale, and these will require a more comprehensive and long term understanding. The ongoing research into the conceptual evolution and modelling of the development of the Chines...
is making significant progress in developing such a framework of understanding. By studying the links between the hydrological and geomorphological development of the Chines, with the habitats and ecology, management decisions can be made with a sound appreciation of the functioning and future development of the Chines, and the interactions between the decision and its consequences.

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REFERENCES


