

# Seamless SDI Model – Bridging the Gap between Land and Marine Environments

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## Abstract

With climate change, rising sea levels pressing harder year on year and the need to manage our resources more carefully in this dynamic environment, the inability to integrate land and marine base information is an increasing problem in many countries. The absence of a seamless spatial data framework prevents the execution of standard practice of locating and referencing spatial data across the land-marine interface where so much pressure and development is taking place. There is a growing and urgent need to create a seamless SDI model that bridges the gap between the terrestrial and marine environments, creating a spatially enabled land-sea interface to more effectively meet sustainable development objectives. This article discusses drivers for integrating land and marine environments and proposes a seamless SDI model as an abstract level SDI and its associated components. This is followed by issues and challenges that must be overcome in developing an overarching architecture for a seamless SDI that allows access to and interoperability of data from marine, coastal and terrestrial environments.

**Keywords:** Spatial Data Infrastructure (SDI), Seamless SDI, Interoperability, Land-sea interface.

## 1. INTRODUCTION

Due to the high economic value of coastal and marine activities, and to the social value of coastal zones for quality of life, managing the coastal zone is a key component of the socio-economic framework in most nations with coastlines. In recent times several natural disasters hit some part of the coastal areas around the world in particular small islands and archipelagic countries causing hundreds thousands of people lost their lives, while those who survived had lost their properties. Moreover anthropogenic global warming will undoubtedly cause substantial sea-level rise and shoreline movement during this century and beyond. Current climatic models predict a global rise in sea level of six meters or more due to climate change. This will affect the rights, restrictions and responsibilities of both governments and individuals who own or manage land along the coastal strip. This is especially problematic in some pacific island states that may be wholly inundated with a six meter rise.

Learning from such kind of devastating disasters, it is important to have accurate, complete and up-to-dated spatial data resources and services of coastal area for better development planning and timely disaster management. Spatial data infrastructure (SDI) as an enabling platform can facilitate access and integration of different datasets from different disciplines. In addition, sustainable development also requires integrated and comprehensive spatial data throughout the country both land and marine area, that can easily be found and accessed by the public.

However, current SDI design focuses mainly on access to and use of land related datasets or marine related datasets. Most SDI initiatives stop at the land-ward or marine-ward boundary of the coastline, institutionally and/or spatially. Consequently, there is a lack of harmonised and universal access to seamless datasets from marine, coastal and land-based spatial data providers. This leads to inconsistencies in spatial data policies, data creation, data access, and data integration across the coastal zone. The extension of a national SDI covering the land and marine environments on a seamless platform would facilitate greater access to more interoperable spatial data across the land-marine interface enabling a more integrated and holistic approach to management of the coastal zone.

This article aims to discuss the drivers for integrating land and marine environments and the potential for adding a coastal dimension to an SDI to facilitate coastal zone management. It also proposes a seamless SDI model as an enabling platform to increase the efficiency and effectiveness of management across regions and disciplines followed by an introduction to its associated components and specifications. Finally it highlights the issues and challenges that must be overcome in developing an overarching architecture for a seamless SDI that allows access to and interoperability of data from marine, coastal and terrestrial environments.

## **2. DRIVERS FOR INTEGRATING LAND AND MARINE ENVIRONMENTS**

The integration of land and marine base information is an increasing problem in many countries. This especially applies to archipelagos where seawater is the 'bridge' connecting islands. While most of the countries are aware the problem of disconnected land and marine information, few have committed to resolving the problem (Murray, 2007). This is partly due to complexity as it requires two or more organisations and users to identify and address the key issues. The ability to access and integrate data has been identified as a problem by people involved in coastal zone management. Also the development of Integrated Coastal Management (ICM) initiatives has encountered similar problems (Strain et al., 2006). However, the primary drivers for land and marine integration can be categorised into societal and commercial and technological drivers.

### **2.1 Societal Drivers**

The coast as the interface between the land and marine is a unique geologic, ecological and biological domain of vital importance to a vast array of terrestrial and aquatic life forms-including humankind. The importance and value of the coastal zone can not be underestimated. Since early settlement days the coastline has been used in many ways. Largely for transportation reasons, major industrial and commercial centres developed around port cities. Some two-thirds of the planet's population lives in a narrow 400-kilometre coastal band. Demographic trends suggest that coastal areas around the world are undergoing serious population growth pressures. Population growth is the driver behind many, if not most, coastal problems (Brower et al., 2002). This puts more pressure on the land-marine environment through greater demand for development and the resulting increase in effluent and pollution. These problems can no longer be viewed in isolation. There is a need for connectivity and replacing a fragmentation with a collaborative, integrated approach (Toth, 2007).

Society is now using resources and producing wastes at rates that are not sustainable. Oceans and the coastal zone have been used as dumping grounds for many years. For instance population increases along Australia's shorelines and the corresponding industrial development has resulted in a rapid increase in sewage outflow into rivers, es-

tuaries and oceans (Plunkett, 2001). Land-based sources of marine pollution account for around 80% of contamination in the marine environment (SOEAC, 1996). Environmental problems have to be addressed globally.

The Intergovernmental Panel on Climate Change (IPCC) has calculated that by the end of this century, sea levels could rise by up to 89 centimetres and temperatures could rise by between 1.4° C and 5.8°C (<http://www.ipcc.ch/>). Consequently climate change and global warming are a serious threat to coastal areas requiring greater attention to coastal protection and change management. Other drivers are cost and time efficiencies, public expectations coupled with greater awareness and focus on temporal issues and policy drivers such as the European Union Water Framework Directive (2000/60/EC) or other legislation concerned with limiting adverse impact of natural forces and processes.

## **2.2 Commercial Drivers**

The coastal zone is one of the most productive areas accessible to people. However, there are increasingly serious signs that economic uses of our coast are undermining their long term sustainability. For example, overfishing is exhausting and depleting fisheries around the world. In Australia, according to the Bureau of Rural Sciences (BRS, 2002), 11 target species in Commonwealth fisheries were classified as overfished, 11 as fully fished and a further 35 classified as 'uncertain', despite the highly regulated and regarded best-managed fisheries in the world. This overfishing came about partly due to lack of knowledge of the distribution, abundance and biology of the stocks, but also due to inadequate management arrangements resulting in unsustainable catches (NOO, 2002). Additionally, production of offshore oil and gas is declining due to depleting resources. The protection of marine ecosystems and fishery resources can not be tackled by individual eco-systems. There is an economic and social need to manage, explore and exploit the nation's ocean territories in a way that will maximise benefit, while protecting the ocean environment.

## **2.3 Technological Drivers**

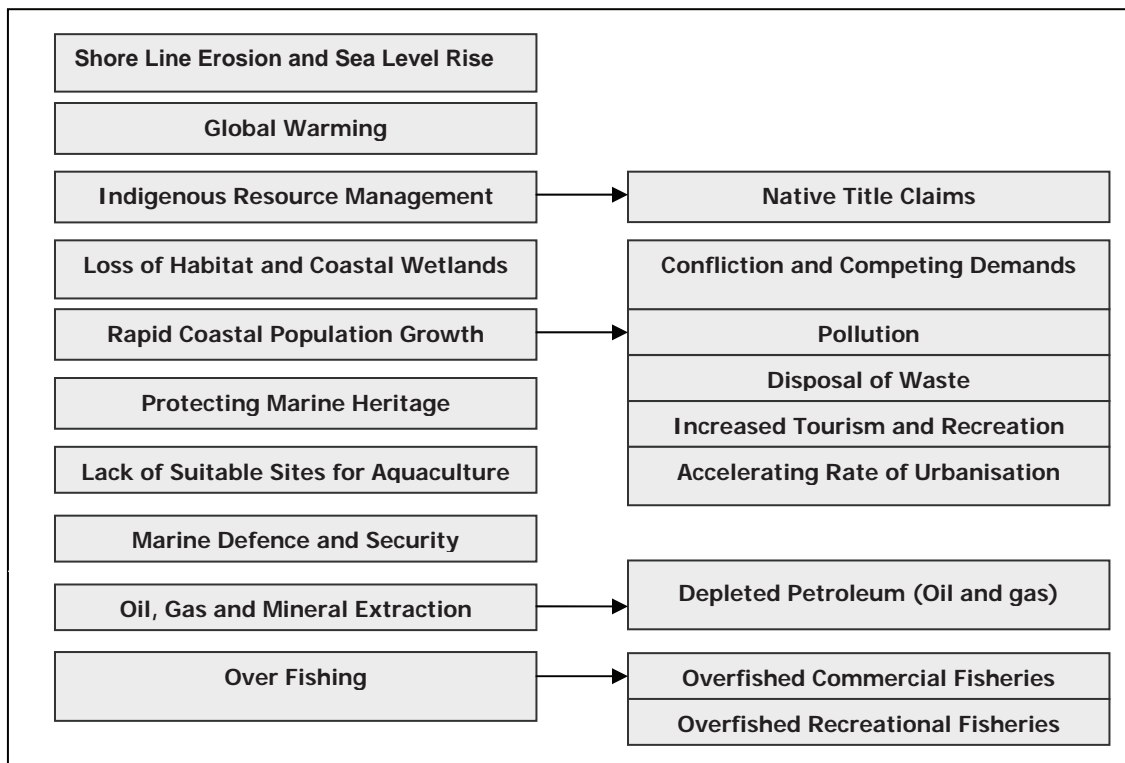
Seamless discovery and seamless use are two main user aspirations. The user would like to be able to search widely, at different levels and access all that exists. This entails the needs for agreements in terms of data descriptions, metadata definitions, protocols, data access and sharing policy. Also the user would like to identify easily the data available and to find easily what fits the purpose and download it directly to their analysis software. Figure 1 illustrates major marine and coastal management issues and challenges and some of their potential impacts.

As the interface between marine and terrestrial environments, coasts have diverse and ever increasing conflicting pressures and demands requiring effective administration and management. In spite of this, current marine and coastal zone management systems are neither effective nor sustainable (Thia-Eng, 2003; Neely et al., 1998). There is a need to make the land and marine infrastructures interoperable so that planning, management and solutions can be identified in a seamless and holistic way.

## **3. SEAMLESS SDI**

An essential requirement for the consistent and effective management of the oceans is reliable, comprehensive and accurate spatial data. The notion that considerable benefits accrue to a society by 'freeing up' access to spatially referenced data has provided

**Figure 1: Marine and coastal management issues.**

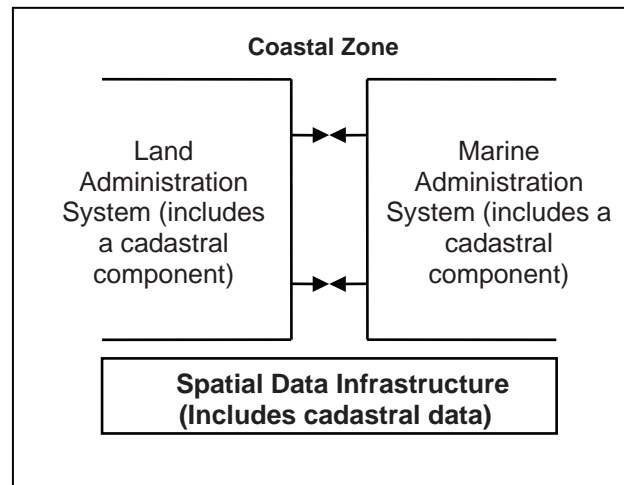


impetus for the construction of local, national, and global spatial data infrastructures (SDIs) (Rajabifard et al., 1999; Rhind, 2001). SDIs theoretically comprise networked, spatially-enabled databases or datasets that are accessible for downloading or manipulation using contemporary technologies, usually according to explicit institutional arrangements and are supported by policies, standards, and human capital (Rajabifard and Williamson, 2001; Nebert, 2004). However, the development of SDIs are confined to the landward or seaward sides of the coastal zone, with little or no thought given to the interaction between these two environments. The reality is that the need for access and coordination of spatial data does not stop at the coastline. Many coastal management issues could be overcome if a spatial data platform that enables a holistic, integrated and coordinated approach to spatial data for decision-making existed.

The complex physical and institutional relationships existing within the coastal zone make it impossible to develop a marine SDI in isolation from land based initiatives. Furthermore a seamless infrastructure aids in facilitating more integrated and effective approaches to coastal zone management, dealing with problems such as marine pollution from land based sources (Williamson et al., 2004). A seamless infrastructure was endorsed by the UN as part of the International Workshop on Administering the Marine Environment (see Rajabifard et al., 2005). It was recommended that a marine cadastre act as a management tool within a Marine SDI (MSDI) as an extension to National SDIs across Asia-Pacific (Figure 2).

In November 2005, the International Hydrographic Organisation (IHO) has organised and conducted a seminar on "The Role of Hydrographic Services with regard to Geospatial Data and Planning Infrastructure". This seminar recognised formally an option for Hydrographic Offices to become responsible or partner in national MSDI and the possible connection of Marine SDI to the National SDI (IHO, 2005). A resolution of the

**Figure 2: Seamless administration system (UN-PCGIAP, 2004).**



17th United Nations Regional Cartographic Conference for Asia and the Pacific (UNRCC-AP) further supported the inclusion and development of a marine administration component as part of a seamless SDI to “ensure a continuum across the coastal zone” (UNRCC-AP, 2006).

On land, issues and challenges such as data interoperability and data integratability have been identified as major issues. However, there are more issues facing marine environment as it is highly dynamic with 4D boundaries. Thus natural resources or features are more likely to move with time which leads to poor accuracy, precision, consistency and completeness of marine spatial data. These difficulties compound in the coastal zone, as it is both the on- and offshore environments combined and interrelated. The Port Philippe Bay (PPB) case study identified land, marine and coastal management issues. Several interviews with organisations involved in the management of PPB were interviewed. Figure 3 shows the conceptual demonstration of issues and challenges of the land, coast, and marine environments. It implies the need for an overarching spatial data framework to facilitate the management of the whole environment.

To improve management of the coastal zone, there needs to be access to and interoperability of both marine and terrestrial spatial data. A more integrated and holistic approach to management of coastal and marine environments would be facilitated by the extension of the SDI on a seamless platform. This would promote data sharing and communication between organisations and facilitate better decision-making. Based on the spatial hierarchical reasoning and object oriented modelling method the seamless SDI model can be postulated as one abstract class SDI at the higher level (parent level) and can be used as a super-class for marine SDI and land SDI classes that extend the abstract class while both land and marine SDI class would inherit seamless SDI properties, they continue to have their specific characteristics and components at the same time (Figure 4).

Just like abstraction is closely related to generalisation, the inheritance is closely related to specialisation. The specialisation and generalisation relationships are both reciprocal and hierarchical. Seamless SDI generalises what is common between land and marine SDI, and they specialise seamless SDI to their own specific subtypes. Figure 5 illustrates a conceptual view of seamless platform architecture.

Figure 3: Issues and challenges of the land, coast and marine environments.

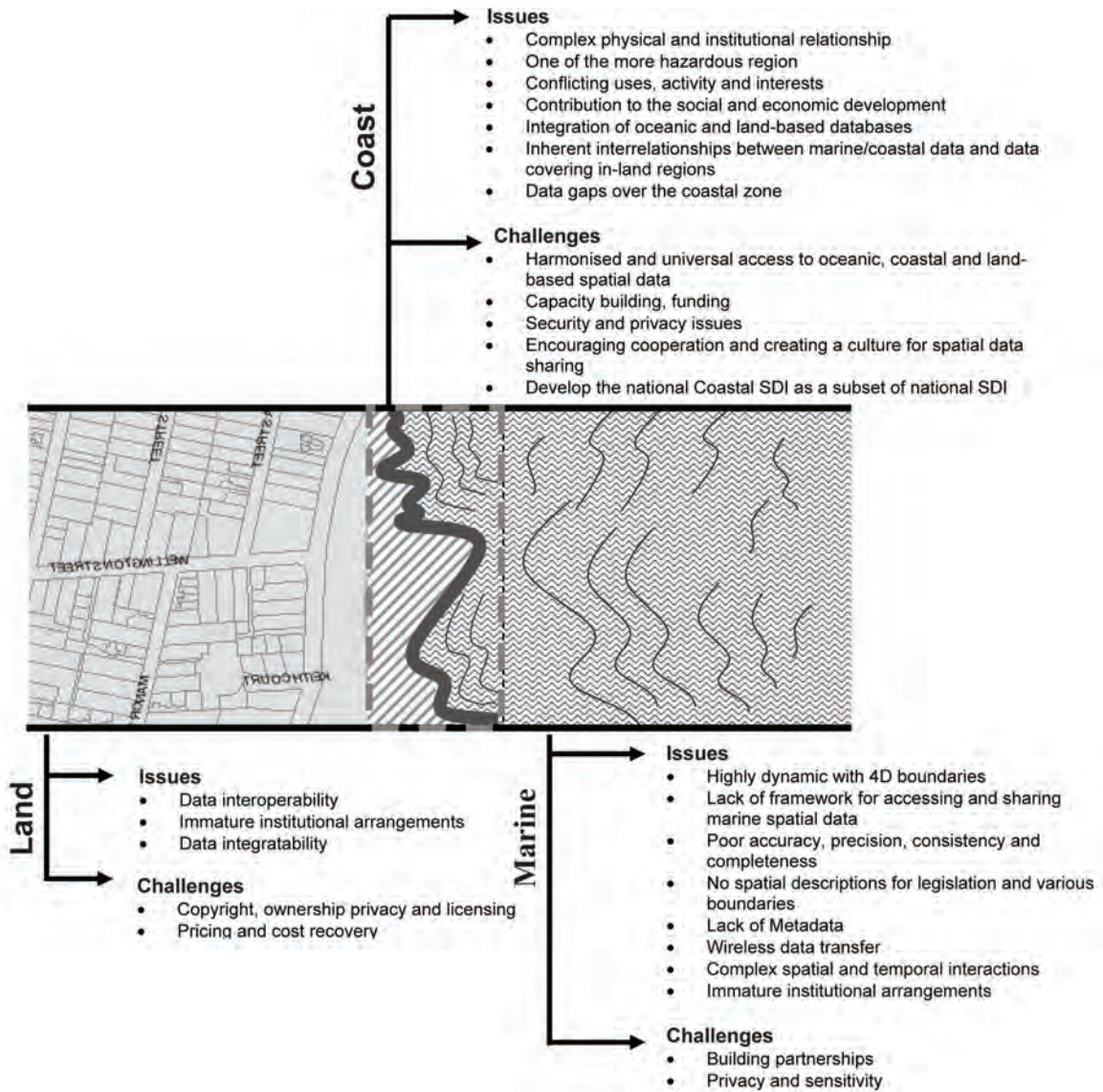


Figure 4: Seamless SDI model.

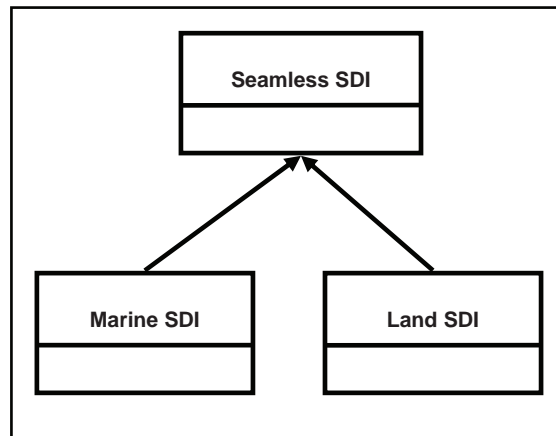
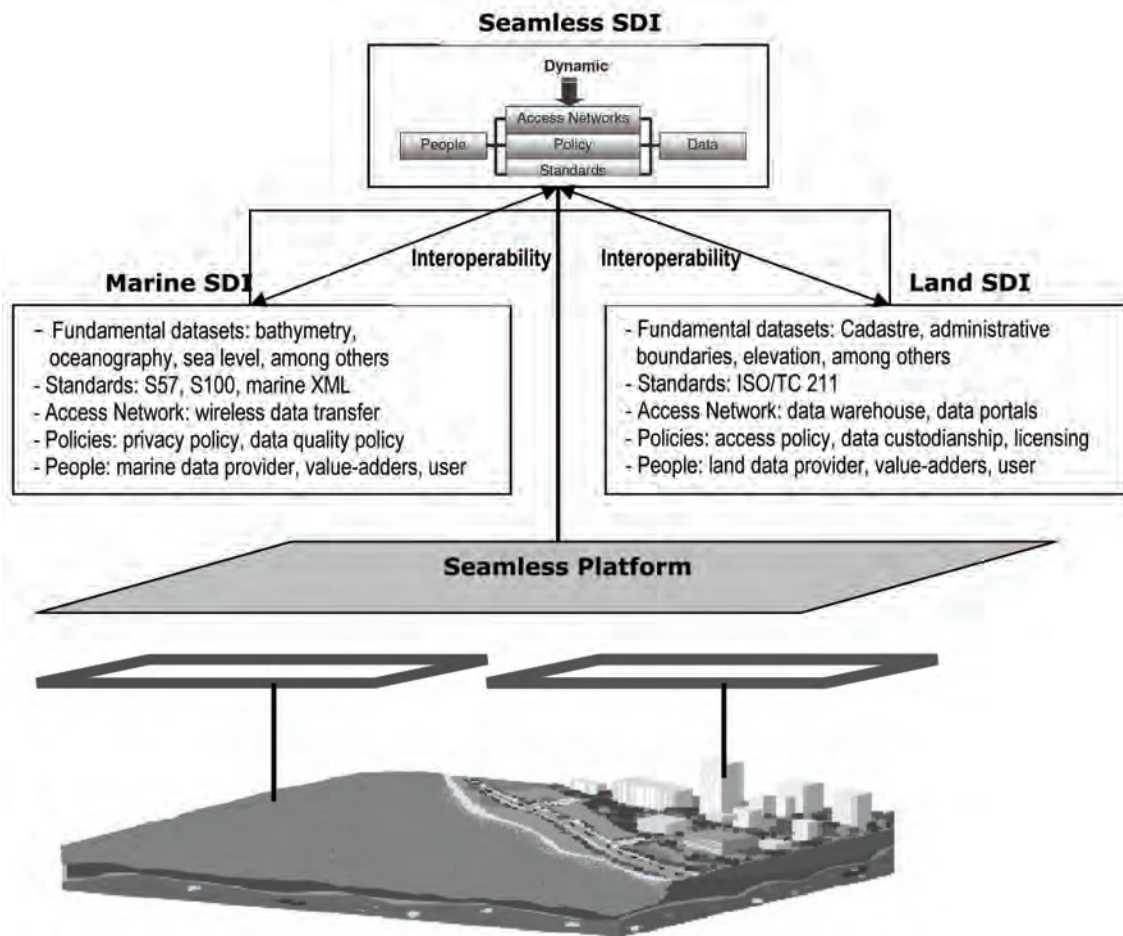


Figure 5: Seamless platform.



A seamless SDI should have the following characteristics:

- Seamless: the digital spatial data is stored continuously throughout and across jurisdictions;
- Multi-purpose: the same data can be used for different purposes;
- Multi-users: the same data can be accessed by different users concurrently, and
- Interoperable: the data stored in the database can be accessed using different GIS software and applications.

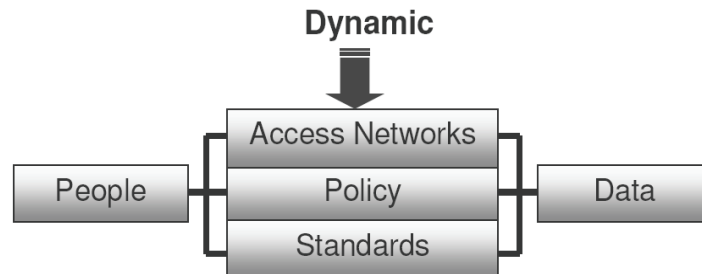
A seamless SDI platform would enable the utilisation of common boundaries across the coastal zone to ensure no ambiguity exists and no areas are unaccounted for over the coastal interface. This infrastructure will become a powerful information resource for managers in fields as varied as fisheries habitat management, pollution monitoring and control, shoreline erosion, weather forecasting and tourism development. The information derived from such a fully integrated information infrastructure will facilitate improved decision making at all levels.

#### 4. SEAMLESS SDI COMPONENTS

The SDI concept has been used to describe land related spatial data and recent initiatives such as marine SDI, marine cadastre and marine spatial planning have all

emerged in response to a global realisation of the need to improve management and administration of the marine environment. Figure 6 shows the components of SDI that link people to data: the standards, policies and access networks.

**Figure 6: Components of SDI (Rajabifard, 2002).**



This section examines each component of SDI (data, standards, policies, access networks and people) and discusses its applicability to seamless SDI. It is important to note that the concept is dynamic, in that it provides an ability to be updated with changing technology or human attitudes or with the need for including new environments.

#### 4.1 Fundamental Datasets

The lack of accurate information seamlessly crossing the land-sea interface creates a serious obstacle for coastal zone managers. These managers need precise, accurate, and timely data and products that are easily accessible and usable for a wide variety of applications. In the land environment an SDI includes 'fundamental datasets', those that will be needed to support most business processes, with a designated custodian responsible for managing them. The seamless SDI model as an infrastructure at the higher level needs to cover all the fundamental datasets from land, marine and coastal environments.

This aligns with the INSPIRE Directive consisting of 34 spatial data themes required to successfully build environmental information systems. The integration of land and marine data is applicable to a number of themes in Annex I-III across the land and marine environments such as the elevation, hydrography/hydrology, transport networks, protected sites, buildings, land use, oceanographic geographical features, utility information, addresses, and geology. Other relevant themes are: environmental monitoring facilities, area management, natural risk zones, sea regions, bio-geographical regions, habitats and biotopes, species distribution and energy resources.

Furthermore, the IHO Marine SDI Working Group (MSDIWG) defined marine SDI as the component of national SDI that encompasses marine geographic and business information in its broadest sense covering sea areas, inland navigable and non-navigable waters. This would typically include seabed topography, geology, marine infrastructure (e.g., bathymetry, wrecks, offshore installations, pipelines and cables); administrative and legal boundaries, areas of conservation, marine habitats and oceanography.

In some countries like USA, national SDI bathymetry is a sub layer of the elevation fundamental dataset. Also INSPIRE Annex III elevation dataset includes bathymetry and shoreline. This may be possible for other datasets. However, it is likely there will be datasets that are fundamental only for the marine environment (i.e. salinity, waves, and water quality).



## 4.2 Standards

SDI must be based on interoperability (seamless databases and systems). Standards are used to ensure interoperability and integratability of different datasets (Strain et al., 2006). The implementation of spatial standards at national level will assure that every institution and organisation creates spatial data in the same manner and it will ease spatial data sharing and exchange. These must be developed using international procedures and practises to cover not only the national needs, but also cooperation at an international level. In this respect the IHO has an important role to play in developing the appropriate standards needed for its hydrographic and cartographic applications, in close cooperation with appropriate organisations responsible for standardisation, such as ISO.

The development of S-100 (the next edition of S-57) has been a great step toward creating a seamless SDI. S-57 standard, although limited in scope and implementation, provides important compatibility for data sharing in the hydrographic information community. The next edition of S-57 standard will not be a standard just for hydrography, but will have manageable flexibility that can accommodate change and facilitate interoperability with other GIS standards. It will also allow hydrographic offices to use other sources of spatial data. S-100 is being based on the ISO/TC211 base standard and will make provision for imagery and gridded data in addition to the existing vector data, defined in the present version. This will facilitate the development of additional products and services other than for navigation purposes (Maratos, 2007). It also plays a key role for IHO and hydrographic offices in any marine SDI development. Therefore common standards and well documented metadata are essential for data discovery, management and compatibility within an SDI.

## 4.3 Policies

Other issues also need to be considered, including the need for harmonised data access policies and exploitation rights for spatial data, data custodianship, conformity, quality, content, industry engagement, avoidance of duplication and sensitivity. These policies for terrestrial spatial data and marine and coastal spatial data are likely to differ in terms of data quality, data access and privacy. Privacy over spatial data in the marine environment is a concern with many countries reluctant to share spatial data relating to their marine jurisdictions. As such there may be a need to maintain the different privacy policies for offshore data (Bartlett et al., 2004).

Appropriate policy and governance models could assist SDI development in several ways: by stimulating more rapid evolution of SDIs, by addressing current deficiencies in the application of standards, and by helping to achieve an increase in public penetration of SDI related technology and services through more tightly integrating a user-perspective in both SDI design and operational management. Therefore there is a need for an appropriate policy model to create a seamless infrastructure across jurisdictions.

## 4.4 Access Networks

Decisions affecting coastal environment need to be timely and based on a strategic interpretation of all available data, presented in an easy and accessible format. Access networks usually comprise data warehouse, data portals, one-stop shops, on-line atlases or similar. For the access network to support interoperable and coordinated data they must comply to SDI standards and policies.

The OGC/TC 211 implementation specifications have deficiencies particularly in relation to manipulating marine data types which typically have 3 or 4 dimensional components (e.g. latitude, longitude, depth, and/or time). For instance, based on the Australian marine SDI activities, it was difficult to deal with the time dimension in OGC Web Map Services (Finney, 2007). A lack of reference implementation for combinations of specific standards is problematic for communities that need to implement these international standards.

#### **4.5 People**

Developing an agreed interoperable framework requires organisational collaboration and a clear use case and applications addressing interoperability cross borders and cross sectors (land-marine) scenarios. An overarching framework is supporting data policies, data access, data specifications (datum, feature catalogue) and standard implementation.

An international workshop for land and marine integration in March 2007 identified the need for a single body to support land-marine integration for the region to keep the land and marine communities working together was noted (<http://www.eurocdr.net>). However, many issues and challenges could be overcome through better coordination arrangements and existence of a single management authority or forum for collaborative planning, and deficient legislation. More information about seamless SDI is required to have a better understanding and knowledge about SDI among different institutions and organisations and there should be proper regulation to enforce that all spatial data providers should involve in and contribute to the development of a seamless SDI.

### **5. CHALLENGES IN CREATING A SEAMLESS SDI MODEL**

In order to create a seamless SDI across terrestrial and marine environments and jurisdictions, it is important to recognise and accept that building and maintaining an SDI is not easy, even for well-developed states. It is a dynamic and complex process at different levels of government and requires research and collaboration with academia and private industry.

Sustainable development requires an integrated spatial data system which provides built and natural environmental datasets that are available to the public. The integration of spatial data at national level encounters several problems either of technical, institutional or policy nature.

#### **5.1 Technical Issues**

Spatial data may come from various sources or data providers. Each data provider has its policies and methods of managing spatial data. Often, land and marine data products are incompatible in terms of scale, projection, datum and format (Gillespie et al., 2000). Several technical issues that should be taken into consideration when integrating spatial data from various data sources are: differences in spatial reference system (horizontal datum, vertical datum, and coordinate system), storage format, scale of data source, feature or object definition (feature catalogue), spatial data quality due to the differences of resolution or data acquisition method and finally differences in spatial data modelling (geometry, features name, attributes, field type, topology) (Syafi'i, 2006). In the MOTIIVE project these problems were also recognised by coastal managers in Europe regarding data. They added the lack of metadata and correspondingly difficulties to discover data (see <http://www.motive.net>).

One more concern linked to the establishment of seamless SDI is the issue of a national shoreline. As the fundamental boundary for so many applications and studies, the lack of a consistently defined shoreline has frustrated coastal zone managers, planners, and scientists for many years. Different representations of the coastline in marine and land datasets leads to data overlaps while most of the applications require a single seamless layer with no duplication of common features. Table 1 shows an example of the differences on several aspects of two main data sources (Topographic Map and Nautical Chart) of Australia that should be considered when integrating land and marine spatial data.

The lack of standardisation and guidance for data and metadata and associated publishing protocols is the main problem of the above differences. Each organisation creates spatial data for its own purposes using their own technical specification without considering that the data may be shared or distributed to other communities.

**Table 1: Different aspects of land and marine spatial data integration.**

Item	Topographic Map	Nautical Chart
Coastline	- Mean Sea Level (MSL) which is determined by modelling the topography	- Local Astronomic Tide (LAT)
Horizontal Datum	- GDA94 - WGS84	- GDA94 - WGS84 - AGD66
Vertical Datum	- AHD (Australian Height Datum or Mean Sea Level) for land elevations. - no depth information	- Mean Sea Level (MSL) for land elevations - Chart Datum for depth - information: LAT, ISLW
Projection system	- Universal Transverse Mercator (UTM).	- Mercator
Digital Storage Format	- Various format (DWG, ARC, SHP, Hardcopy )	- Digital Nautical Charts: Raster(TIFF, ECW) - Electronic Navigation Chart: DIGITAL - S-57 Version 3.1 - Nautical Chart: Digital and Non digital - Raster HCRF V2 / GEOTIFF V1 (not to be used for navigation), Hardcopy Printed Charts - Bathymetric Map: Digital and Non digital-ASCII, Hardcopy - Printed maps
Scale	- Systematically (1 to 10K, 25K, 50K, 100K, 250K)	- Not Systematically (range from large scale to small scale)

## 5.2 Institutional Issues

There are several non-technical issues that should be overcome to develop a seamless SDI. The coastal zone is difficult to manage due a complex array of legislative and institutional arrangements varying from local to global levels. Furthermore, there is currently confusion about the management of the land-sea interface. This shows, for example, in Australia where local governments manage land to High Water Mark (HWM), and state governments manage the marine environment from the Low Water Mark (LWM). This means that there are no overlapping arrangements in place to enable efficient coastal zone management. There is also a strip of land between the two boundaries which is not within a management jurisdiction at all (Binns and Williamson, 2003).

Results from European Spatial Data Research (EuroSDR) questionnaire sent out to all European mapping agencies and hydrographic offices and geological organisations in late 2006 showed that only in a small number of cases the land and marine data is managed by a single organisation. In others collaboration across two or more organisations is required (typically national mapping agency, hydrographic office and sometimes the geological organisation) (Murray, 2007). Institutional integration increases the efficiencies and effectiveness of the management in any jurisdiction with land and marine environments. If national mapping and hydrographic charting agencies are separate, they need to work under the same banner and their policy should align with each other and the national policy to create a seamless SDI.

National mapping agencies and hydrographic offices use different coordinate systems, projections, horizontal and vertical datums and contents. Therefore users can not reference any object consistently across the coastal zone. A common framework will support interoperable coordinate systems and datums, interoperable objects along agreed boundary and interoperable feature catalogues. This agreed interoperable framework will contribute to the seamless SDI.

Immature institutional arrangements result in organisations working in the same jurisdiction or in the same discipline collecting similar data in different ways, engage in much duplication of effort, suffer from insufficient or inappropriate standards, are insufficiently aware of methods that should be used, or of the availability of existing data.

### **5.3 Policy Issues**

The population and development pressures that coastal areas experience generate several critical problems and policy issues and raise serious and difficult challenges for coastal planners. A coastal state may be a party to many international conventions (i.e. RAMSAR, MARPOL, and London Convention) in addition to developing its own national, and even state or local regulations. Activities and resources are usually managed in a sectoral and ad-hoc approach with legislations or policies created when the need arises and specific to only one area of interest (Strain et al., 2006).

In many parts of the world, access to detailed information about the coast is considered a very sensitive issue, primarily due to concerns over national security. These restrictive policies lead to coastal data being withheld from stakeholders and the general public. Accordingly this complex, fragmented regulating framework for marine and coastal management causes the inability to adequately handle the pressure of different activities and stakeholders within the coastal zone.

The development of a framework such as a seamless SDI would aim to aid in facilitating decision making to respond to these technical, institutional and policy issues, to facilitate more effective management of the land sea interface.

## **6. CONCLUSION**

In the terrestrial domain, the need to share and integrate spatial data for more efficient resource information management has been recognised for over a decade. There is now increasing recognition by the public at large of the need to support sustainable development of both the coastal and marine environments. The practical implementation of a marine SDI is mainly occurring separate from the terrestrial SDI, using the same components but adapting them to suit the different environment. However the multidisciplinary interactions in the land–sea interface require sophisticated information infra-

structures that not only do not yet exist, but which will not appear if disciplines continue to develop their SDIs in isolation from one another. Research now needs to focus on combining these initiatives and developing a seamless SDI as one abstract class SDI at the higher level. The development of a seamless SDI will ensure this data is interoperable and thus improve decision-making and administration in the coastal and marine environments. However, the differences in the marine and terrestrial environments in fundamental datasets, data collection and technology used in these environments will make interoperability and integratability between marine and terrestrial spatial data a big challenge.

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