

## Software Reuse to Support Earth Science

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## 支持地球科学的软件复用

**摘要:**地球科学研究中数据的准备、分发、访问、处理和分析都依赖于计算机软件。科学结果的重复通常需要复用同样的软件。同样,科学数据的有效分发、访问或者分析也都需要进行软件复用。地球科学软件开发社区已经意识到了软件复用的价值,并且在社区内大力鼓励和培育软件复用。因此,他们成立了 NASA 地球科学数据系统(ESDS)软件复用工作组(WG)来支持社区成员之间的软件复用。工作组开发了软件复用门户来发布软件复用相关的信息、资源,并且提供培训来提高和改进整个社区的软件复用实践。工作组还开发了一个复用支持系统(RES)原型系统来支持可复用软件的访问。此外,工作组还制定了复用成熟度级别,从而提高了评估和选择可复用软件的能力。

**关键词:**软件复用社区;科学软件;数据管理;地球科学;复用支持;复用成熟度

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**Abstract:** Earth science relies on software to prepare, distribute, access, manipulate and analyze data. Scientific replication often requires reuse of the original software. Similarly, efficiently distributing, accessing or analyzing scientific data often requires software reuse. Recognizing the value of software reuse, the Earth science software development community has encouraged and fostered reuse within the community. The NASA Earth Science Data Systems (ESDS) Software Reuse Working Group (WG) was established to support software reuse among members of the community. The WG developed the software reuse portal to inform the community about reuse issues and available resources and educate the community on improving software reuse practices. Requirements for a Reuse Enablement System (RES) have been developed and are being used to implement a prototype system to provide access to software for potential reuse. Reuse Readiness Levels are being developed to document

criteria and improve capabilities for evaluating and selecting software for potential reuse.

**Key words:** software reuse community; scientific software; data management; Earth science; reuse enablement; reuse readiness

## 1 Introduction

Scientific practices evolve over time, and like other scientific communities, the Earth science community relies on software to prepare, distribute, access, manipulate and analyze data collected for scientific investigations. The need to replicate scientific studies for comparative and longitudinal analysis often requires reuse of the original software that was used to prepare, manipulate and analyze the data. Reuse of software and related artifacts also offers potential opportunities to improve software quality, maintainability and costs<sup>[1,2]</sup>. Likewise, the distribution, access and analysis of Earth science data could benefit from software reuse. In recognition of the value of software reuse for achieving its goals, the Earth science software development community has engaged in several efforts to encourage and foster reuse within the community.

As part of its efforts to assist the Earth science community, the National Aeronautics and Space Administration (NASA) created the Earth Science Data Systems (ESDS) working groups to address the needs of developing, operating, and maintaining large data systems for Earth science research. The Software Reuse Working Group (WG) focuses on addressing the issues required to enable and facilitate the reuse of software assets within the NASA Earth science community<sup>[3]</sup>. The WG is involved in a number of activities in various areas that are designed to encourage and enable reuse among the community of Earth science software developers. These include reuse implementation projects, support and enablement activities, education and public outreach, policy change activities, and reuse incentive activities. Section 2 provides an introduction to the NASA ESDS Software Reuse WG and its activities. Due to

space constraints, the rest of the paper focuses on a few major activities for encouraging and enabling reuse within the community: the development and maintenance of a software reuse portal web site (Section 3), the recommendation for the creation of a Reuse Enablement System (RES) and work towards developing a prototype RES (Section 4), and the development of a set of Reuse Readiness Levels (RRLs) to measure the maturity of software in the sense of reusability (Section 5). Section 6 concludes with a summary of these and other activities, and gives a brief description of planned future work that will continue to encourage and enable software reuse among the community of Earth science software developers.

## 2 Background of the Working Group

NASA's ESDS Software Reuse WG began in 2004 as an outgrowth of the Strategic Evolution of NASA's Earth Science Enterprise (ESE) Data Systems (SEEDS) formulation process<sup>[4]</sup>. The purpose of the group is to facilitate reuse of software assets within the NASA Earth science community. Membership is limited to NASA-funded projects and investigators, though there have been many contributions from the general Earth science community. For over three years, the WG has been working to establish a "marketplace" for reusable Earth science software artifacts. A key way of enabling this marketplace is to increase the supply and availability of reusable assets. Also, by demonstrating the feasibility and value of reuse, the WG has worked to increase the community capacity and desire for reuse. The WG interacts remotely monthly and at least once a year face-to-face. A core support team that includes full-time support staff plays a key role in keeping the WG

moving forward, providing key input, and based on input from WG members, developing studies, documents, and recommendations. The support staff also maintains the WG portal web site and is developing a prototype Reuse Enablement System (RES). Together with the full WG, the support team is helping to develop a set of Reuse Readiness Levels (RRLs) and refine them based on feedback offered by the Earth science community. A number of WG recommendations have been well received by NASA headquarters, including the creation of the portal web site and the updating of wording in NASA funding opportunity announcements to encourage software reuse.

### 3 Earth Science Software Reuse Portal Web Site

One of the primary endeavors of the WG has been the establishment, operation, and continuing enhancement of a portal web site for Earth science software reuse<sup>[5]</sup>. The Earth Science Software Reuse portal has been developed to increase understanding and awareness of software reuse among members of the Earth science community and other scientific communities who could benefit from software reuse by informing them about software reuse issues and available resources, as well as educating them on techniques for improving software reuse practices. The concept for the portal grew from the recognition that mass communication capabilities are needed to meet these goals for education and outreach to the community of Earth science software developers. Since its public launch early in 2005, increasing visits to the portal, along with comments received from the community, indicate that the portal has helped the WG make progress on achieving these goals. As of March 2008, over 12 000 unique visitors, which includes over 1 500 repeat visitors, have visited the site more than 17 000 times, resulting in nearly 58 000 page views since statistics collection began in December 2005. On average, the site has over

600 visitors per month, many of whom find the site through its high placement in the results of web searches for “software reuse” in search engines such as Google, Yahoo and MSN Search.

#### 3.1 Portal Development

The Earth Science Software Reuse portal was initially developed and implemented on a NASA server, then ported to the ESDS WG server in 2007. The portal was developed using open source software, including the Plone content management system<sup>[6]</sup> and the Zope web application server<sup>[7]</sup>, and was built upon other open source software, such as the Linux operating system<sup>[8]</sup>, the Apache web server<sup>[9]</sup>, and the Python programming language<sup>[10]</sup>. The choice of open source software for the portal reflects the WG’s preference for open source software, which the WG has relied on for the development of the portal and which the WG also recommends to those considering software for potential reuse. The development and initial implementation of the Earth Science Software Reuse portal demonstrates the reuse of open source software for the portal as both a recipient of software reuse and a contributor to software reuse<sup>[11]</sup>.

The members of the WG operate, enhance, update, and routinely monitor the portal to identify broken links and incorrect or outdated information. In addition, an online suggestion form, available from various sections of the portal, enables visitors to provide comments, anonymously if desired, to suggest content, links, corrections, or other improvements for the portal.

#### 3.2 Organization of Content

The content of the Earth Science Software Reuse portal is organized around a home page, which features news and upcoming events, and offers access to sections labeled reusable assets, resources, open source, and funding opportunities. News items report on pending deadlines, recent WG activities, updates to the portal, and recent events and publications of interest to the WG. Upcoming

events include notices about conferences and meetings from the event calendar, which have been designated relevant to scientific software reuse or have been attended previously by members of the WG. The open source section contains a brief description of open source software and the open source model for software development, offers the WG's perspective on open source software, and contains links to other sites that provide additional information and perspectives on open source software. The section on

funding opportunities contains links to pages that list announcements about available funding for projects related to Earth science and reuse that are accessible from NASA and other government agencies. All of these sections are intended to encourage and enable software reuse within the community of Earth science software developers by providing information on reuse and resources to assist in reuse efforts. Fig.1 shows the home page of the portal web site and the basic organization of the content.

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Software Reuse  
Working Group**

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**news**

- New Awards Section  
2008-04-14
- Reuse Enablement System (RES) Documents Added  
2008-02-28
- 6th ESDS WG Meeting Reuse Materials Posted  
2007-10-31
- Draft Agenda for 6th Joint ESDS Working Group Meeting Available  
2007-09-19
- Prototype Internal NASA Reuse Enablement System in Development  
2007-09-10

More news...

**upcoming events**

- 10th International Conference on Software Reuse (ICSR10)  
Beijing, China, 2008-05-25
- AGU 2008 Joint Assembly  
Fort Lauderdale, Florida, 2008-05-27
- TeraGrid '08  
Las Vegas, Nevada, 2008-06-02

**Earth Science Software Reuse**  
last modified 2008-04-14 10:42 AM

Welcome to the Earth Science Data System (ESDS) Software Reuse Portal. Please visit the [ESDS Working Group Page](#) for more information about our group.

We have posted some [reuse definitions](#) about what the Working Group does and does not consider reuse in our Resources, Library section, along with a [brochure](#) about our group and its activities. A number of [bottom-up reuse guidelines](#) are now available in the Resources, Guideline Documents section. We have also added a [technology transfer guideline](#) and [technology transfer FAQ](#) to help explain NASA's technology transfer process in the same section of the site. Some of our more recent [publications](#) have been added to the Resources, Library, Publications section, while the [S4PM case study](#) and the [SOSE case study](#) have been added to the Resources, Library, Case Studies section. A few new [non-NASA funding links](#) are on our Funding Opportunities page. Materials presented at the [6th ESDS WG Meeting](#) in October 2007 are now available, including some early work on drafting Reuse Readiness Levels (RRLs). The slides used for our discussion of [RRLs at the 2008 Winter ESIP Meeting](#) are now available in the Resources, Events, Event Highlights section. Our full list of upcoming [events](#) is also in the Resources section, and we have added a list of some [awards](#) that are relevant to reuse projects in a new folder in the Resources section.

We have completed our survey to better understand the practice of software reuse within the Earth Science community. Preliminary [survey findings](#) are available on the web and have been published in a [2006 IGARSS paper](#). We have also posted some of our documents related to our proposed [Reuse Enablement System \(RES\)](#) in a new folder under the Resources section. Our trade study of existing systems, use cases for the proposed RES, and requirements for the proposed RES are currently available.

For more information, please visit our [News](#), [Site Map](#), [About Us](#), [FAQ](#), [Suggest Content](#) and/or [Contact](#) page.

**Developing an internal marketplace for reusable software development artifacts**

**Demand**

- Demonstrate the feasibility and value of reuse through focused projects
- Increase community capacity and desire (knowledge & tools) to reuse existing assets

It should be as easy to find a good quality reusable software asset as it is to

Fig.1 Software reuse portal-home page

### 3.3 Description of Resources

The collection of resources includes categories for references to books and articles, events, projects, tools, and technologies, as well as other sections relevant to software reuse. Many sections in the portal's collection of resources are updated regularly, reflecting ongoing WG activities as well as suggestions received from WG members and other portal visitors. The WG utilizes a peer review process to select items for inclusion within the various sections of resources and follows style guides to update each section consistently. This section of the site is designed to encourage reuse by distributing information that will help developers and reusers in their efforts.

#### 3.3.1 Books and articles

The section on books and articles displays online catalogs that list references to literature relevant to reuse and on topics of interest to Earth science data system developers. These catalogs are updated as a result of suggestions offered by WG members or by portal visitors who use the online suggestion form to recommend items for inclusion on the portal. Suggestions for references are initially reviewed by the portal administration team for relevance and, if potentially relevant, are presented to the WG as candidates to be considered for inclusion in the appropriate catalog. WG members volunteer to review recommended books or articles of interest and consider relevance of the content to the WG, whether the item was published in a peer-reviewed journal or proceedings, and whether it is accessible online. Each reviewer prepares a report about the item, and if reports from three reviewers recommend including a nominated item in a catalog, a reference for the item is created.

#### 3.3.2 Events

Similarly, suggestions are received, either from WG members or from online submissions, for no-

tices of events to be included on the events calendar. If applicable, nominated recommendations are reviewed by the WG. If three members recommend posting an announcement of a particular event, an entry describing the event is included on the calendar. Recurring events that have been listed previously do not need to be reviewed again in order to be re-listed. Minimally, notices of events include the event title, venue, meeting dates, and the URL if known.

#### 3.3.3 Library of WG material

The collection of software reuse resources also includes resources developed by WG members that are hosted on the portal server. Examples of hosted resources include a library of publications and presentations by WG members, case studies that serve as examples of reuse by WG members, and WG documents that record WG decisions and activities. Another example of hosted resources is the set of guideline documents that serve as brief primers on issues pertinent to software reuse. Taking a bottom-up approach, the topics included among the guideline documents cover various issues that were suggested by WG members and the Earth science software development community as areas in which brief guidance documents would contribute to software reuse practices.

#### 3.3.4 Guidelines

The Bottom-up Reuse Guidelines have been developed by several WG members to meet community needs that have been identified as gaps in understanding where knowledge sharing could improve reuse practices. For example, a survey of the Earth science community found that concerns for intellectual property presented potential barriers to software reuse<sup>[12]</sup>. Many of the software reuse guidelines topics were presented and discussed by their authors during WG meetings to address these gaps. Topics of the guideline documents developed to date include

documentation<sup>[13]</sup>, hierarchy of reuse<sup>[14]</sup>, intellectual property<sup>[15]</sup>, metadata<sup>[16]</sup>, object-oriented programming<sup>[17]</sup>, packaging<sup>[18]</sup>, virtual globes<sup>[19]</sup>, technology transfer<sup>[20]</sup>, and Frequently Asked Questions (FAQ) related to technology transfer<sup>[21]</sup>. This section of the portal was designed specifically to assist developers in making their software more reusable by describing, for each of the different topics presented, practices for improving the reusability of software.

### 3.4 Description of Reusable Assets

The reusable assets section of the portal contains a small catalog that briefly describes and provides links to collections of reusable software and other information assets of potential interest to the community of Earth science software developers. These collections of reusable assets, recommended by WG members for inclusion on the portal, are offered to make it easier for users to find reusable Earth science software, thus encouraging them to reuse these assets in their own development projects. However, since surveys of the Earth science community conducted in 2004 and 2005 showed that having a catalog/repository for reusable Earth science software would increase the amount of reuse within the community<sup>[22]</sup>, the indication is that existing catalogs and repositories are not sufficient to meet the community's needs. Therefore, the WG has proposed the creation of a Reuse Enablement System to address the shortcomings of existing systems and meet community needs.

## 4 Reuse Enablement System (RES)

### 4.1 Background

Realizing the many benefits of software reuse for the Earth science community has been challenging. To better facilitate reuse within the Earth sciences, the WG recommended the creation of a Reuse Enablement System (RES) to NASA Headquarters. The primary goals for the WG relating to

the RES include facilitating the cataloging and distribution of reusable assets for the Earth science community, evaluating the technology options available for building a RES, implementing a RES based on that evaluation, and developing policies and guidelines for RES operation and management. Potential users of the RES include members of the Earth science community and other scientific communities who develop systems and software applications to foster the collection, dissemination, discovery, access, and analysis of scientific data. Potential asset providers are Earth science data systems and applications developers, especially those who recognize the value of open source software and standards, which the Earth science community has benefited from using<sup>[23]</sup>. The WG also has recommended the establishment of a peer-recognition award for reuse that could be used as an incentive to encourage reuse and recognize members of the community who prepare and submit reusable assets to the RES for use by the community.

As part of its recommendation, the WG estimated the size of the RES target audience and the potential number of assets the RES would contain. The detailed data kept for the civil servant workforce at the Workforce Information Cubes for NASA web site<sup>[24]</sup> indicate that about 4% are in Earth science and about 60% are scientists and engineers. Since the total workforce of civil servants and contractors is about 82 000 people, there is a potential audience of about 2 000 NASA Earth science scientists and engineers. This is a lower limit for the RES target audience, since the NASA workforce represents only a portion of the Earth science community.

Looking to popular repositories of general-purpose software like SourceForge<sup>[25]</sup> provides an estimate of the number of assets the RES could contain. SourceForge has about 172 000 projects and 1 800 000 users. Assuming there is only one unique primary

provider per project, about 10% of the SourceForge users are providers. Based on the above conservative estimate of two thousand RES users, if 10% are providers and each provider offers one asset, then the RES could contain at least 200 assets.

Through the activities described below and numerous meetings and teleconferences, the WG identified the functional requirements needed for a RES to support the Earth science community. Several WG members participated in a workshop and helped draft the initial set of requirements. Over several months, these requirements were refined through weekly and monthly teleconferences and finalized during a review at the October 2004 ESDS WG meeting. The result of this work identified a number of requirements in the following areas: general, search, user registration, asset usage, asset submission, content management, and system administration. The requirements were later formalized<sup>[26]</sup> so that they could be evaluated and tested more easily. Two surveys, a trade study, an architecture study, and current prototype development activities also have informed the development of the RES.

## 4.2 Surveys and Trade Study

In 2004 and 2005, two survey studies were conducted to learn about the reuse practices and challenges faced by members of the Earth science community<sup>[22]</sup>. These studies found that to facilitate the software reuse process, developers need to be able to easily locate and evaluate available reusable assets, and when people did not reuse software, the primary reasons were because they did not know where to look and they did not know such reusable software existed. In addition, the survey results revealed that respondents showed a clear preference for reusing smaller-sized components such as algorithms, techniques, source code, scripts, code libraries, and code fragments. They also showed a preference for using and encouraging more use of

open source software, which generally provides more freedom than traditional, closed licensing mechanisms. The survey results also revealed that a catalog or repository for reusable artifacts is the best means of increasing software reuse within the Earth science community, which would also help address the two major problems noted above (not knowing reusable assets existed or where to locate them). This led to the recommendation to create a RES that would serve as the central location for providing reusable assets to Earth science software developers. The goal is to increase and make more effective reuse within the Earth sciences by providing one location where all types of reusable assets for Earth science work can be found, and encouraging all providers and reusers to make use of this new resource.

In response to its recommendation, the WG was tasked by NASA Headquarters to perform a trade study to understand the roles of the NASA Open Source Agreement web site<sup>[27]</sup> and the Global Change Master Directory<sup>[28]</sup> in cataloging data services, and any other related NASA software sites as a potential platform to enable software reuse for the Earth science community. These two sites and five other NASA sites were reviewed, along with a variety of non-NASA sites performing similar roles. The results of the study showed that none of the evaluated repository or catalog systems satisfy the needs of the community<sup>[29]</sup>. The shortcomings found were mostly in the following general areas: they did not meet most of the critical functional requirements, focus on the Earth science domain, target software developers as their primary audience, or provide the types of small-sized assets that are most useful for Earth science software developers.

## 4.3 Architecture Study

The WG then assessed the architectures of existing catalog and repository systems as options for implementing a new RES. The assessment was con-

ducted to provide recommendations for the reuse of an existing system or software package that could provide most of the desired functionality as the foundation of the RES. In addition, the assessment was conducted to recommend modifications needed for the RES to meet the stated formal requirements. The systems and packages that were evaluated and reviewed as part of this study include GForge, Savane, and XOOFS. Other packages that were examined, but not reviewed in detail, include the Fedora Digital Repository System, JBoss Portal, Liferay Portal, and Repository in a Box. As part of this evaluation, a level of effort estimate was performed for the requirements that the systems or packages did not or only partially meet. The development effort has been based on Barry Boehm's original Constructive Cost Model (COCOMO)<sup>[30]</sup>. The results of the architecture study<sup>[31]</sup> clearly indicate that the XOOFS Content Management System (CMS) satisfied the most requirements for the RES and would require the least development and maintenance effort to satisfy these requirements.

#### 4.4 Prototype Development

The development of the RES was divided into three main builds and one release, each implementing a set of unsatisfied requirements found in the RES Architecture Study's gap analysis<sup>[31]</sup>. Development started with the installation of the base XOOFS CMS<sup>[32]</sup> and a publicly available module, PD-Downloads<sup>[33]</sup>. This module served as a basic download management tool that would be modified to suit RES requirements. Once installed, this basic system was enhanced through modification of the template files and source files, the addition of new files, and the CMS's built-in configuration options.

The current prototype RES contains functionality specifically tailored to Earth science software reuse. It possesses all the basic features expected in any software repository system such as user accounts/lo-

gins, restricted access, file upload and download, file browsing, and file search, which currently allows searching asset titles and descriptions (which may include keywords or facet descriptions). In addition to these basic features, the system has many specific features to promote reuse, such as an easy method to submit modifications to assets, a system to collect metrics on asset usage, and a commenting system to let users know the advantages and disadvantages of reusing assets. Accessibility and security were also considered from the beginning, as the prototype complies with NASA portal affinity guidelines<sup>[34]</sup> and accessibility guidelines in Section 508 of the Rehabilitation Act (29 U.S.C. 794d)<sup>[35]</sup>, all pages are SSL encrypted, and all uploaded assets are scanned for viruses using the open source Clam Anti-Virus<sup>[36]</sup> scanning tool.

Enhanced functionality and improvements are planned for future releases of the RES. The search feature will allow for filtering by usages or submission date (for example), giving users a much richer searching capability, as well as providing an option for full text search of all code. Also, better version control of asset modifications is planned. Currently assets can be created, modified, deprecated, or deleted permanently. However, there is not a strong connection between multiple versions of an asset. Policies, operational guidelines, and standards for the RES are also being developed and formalized. Although the prototype RES has shown potential to be a valuable tool for the software reuse community, more development and testing is necessary before release and use.

In addition, the WG found that having a measure of reuse maturity for software assets in the RES would be useful in helping users decide which assets are best suited for their needs. However, common measures of technology maturity generally do not address reusability, so the WG is developing

Reuse Readiness Levels (RRLs) as a way to measure the maturity of software in the sense of reusability. As this work progresses, appropriate parts of it are being incorporated into the RES. Currently, a RRL can be added to the software description and a prototype RRL calculator is being developed for determining and displaying the RRL of software assets.

## 5 Reuse Readiness Levels (RRLs)

The maturity of technology can be measured in various ways, and one common method is with Technology Readiness Levels (TRLs) like the ones NASA has produced<sup>[37]</sup>. There are other similar measures, but the ability or readiness of a particular technology to be reused is generally not considered, or only plays a small role if it is. Recognizing the need to measure the maturity of a technology for reuse, the WG is developing a set of Reuse Readiness Levels (RRLs) for the purpose of determining the reuse maturity of software assets. They are modeled after NASA's TRLs, which have been used for many years, particularly for assessing hardware's readiness for spaceflight purposes. The following areas were identified by the WG as main topic areas for assessing software reusability: Documentation, Extensibility, Intellectual Property Issues, Modularity, Packaging, Portability, Standards Compliance, Support, Verification and Testing. Volunteers from the WG drafted the following set of levels for each topic area that describes how reusable software becomes more mature in each topic area.

- Documentation

1. Limited internal documentation available
2. Fully commented source code available
3. Basic external documentation available
4. Reference manual available
5. User manual available
6. Tutorials available

7. Interface guide available
8. Extension guide and/or Design/Development guide available
9. Full software lifecycle engineering design documentation available

- Extensibility

1. No ability to extend or modify program behavior
2. Prohibitive costs and efforts need to modify or extend the system
3. Can be extended with the input of considerable time and effort on par with recreating system separately
4. Can be modified and extended through configuration changes, minimal modification of source
5. Consideration for future extensibility designed into system, extensibility approach somewhat defined
6. Designed from the start to allow easy extensibility, provides many points of extensibility and a thorough and detailed extensibility plan
7. Proven to be extensible internally, code structured to provide loose coupling and high cohesion
8. Proven extensibility on a major external program, provides a clear plan for modifying and extending features
9. Proven extensibility in multiple scenarios, provides specific documentation and features to build extensions

- Intellectual Property Issues

1. Potential owners and stakeholders of product have been identified.
2. Relevant intellectual policies of potential owners and stakeholders have been reviewed.
3. Intellectual property agreements have been

proposed to potential stakeholders.

4. Potential stakeholders have negotiated on intellectual property agreements and authorship issues.
  5. Agreement and approval on authorship, attribution, and intellectual property issues have been obtained from stakeholders.
  6. Authorship, attribution, and intellectual property statements have been drafted to reflect agreement among stakeholders on intellectual property and authorship.
  7. Authorship and intellectual property statements included in product prototype.
  8. Manifestation of authorship, attribution, and intellectual property statements reviewed in product prototype before product release.
  9. Reviewed authorship, attribution, and intellectual property statements packaged with product for release.
- Modularity
    1. No designs for modularity or reuse
    3. Modularity at major system or subsystem level only
    5. Partial segregation of generic and specific functionality
    7. Clear delineations of specific and reusable components
    9. All functions and data encapsulated into objects or accessible through web service interfaces
  - Packaging
    1. Source code available
    3. Detailed installation instructions available
    5. Software is easily configurable for different environments
    7. OS detect and auto-build for supported platforms
  - GUI installation environment provided
  - Portability
    1. The software is not portable at any cost
    2. Some parts of the software may be portable
    3. The software is only portable with significant costs
    4. The software may be portable at a reasonable cost
    5. The software is moderately portable
    6. The software is portable
    7. The software is highly portable
    8. The software is completely portable
  - Standards Compliance
    1. Follows no particular standard
    2. Follows some parts of common standards and best practices
    3. Follows a company-wide standard for development and testing
    4. Most components follow a complete, universal standard, but not validated
    5. All components follow an universal standard, but only partially validated
    6. Validated to follow a specific proprietary standard
    7. Validated to comply to a specific open standard
    8. Proven by validation to comply with a “gold” standard
    9. “Gold” standard compliance of entire system and development, independently validated
  - Support
    1. No support available
    2. Known contact available
    3. Original developers provide proactive support
    4. Latest updates or patches are available but not very frequently

5. Informal user community available
  6. Centralized support available
  7. Organized/defined support by the original developer available
  8. Support by organization available
  9. Large user community with well-defined support available
- Verification and Testing
    1. No testing performed
    2. Software application formulated and unit testing performed
    3. Testing includes testing for error conditions and proof of handling input errors
    4. Software application demonstrated in a laboratory environment
    5. Software application tested and validated in a laboratory environment
    6. Software application demonstrated in a relevant environment (e.g., Earth science related)
    7. Software application tested and validated in a relevant environment (e.g., Earth science related)
    8. Software application “qualified” through test and demonstration (meets requirements) and successfully delivered to the relevant (e.g., Earth science) environment
    9. Actual software application tested and validated through successful use of application output

These topic area levels were placed on a scale from 1 to 9 (shown above) and organized in a matrix to facilitate cross-comparison of levels. By comparing all of the topic area descriptions for a given level, the WG drafted summary levels that combined the nine topic areas into a single set of RRLs. The current draft of the RRLs is shown below in Table 1.

The WG is currently working with the community to get feedback on these levels and to better refine this scale for future usage. Presentations of earlier work on the RRLs received positive feedback from members of the community and some valuable suggestions for improving the levels that the WG is currently addressing. Individual topic areas are being reviewed to improve capabilities for measuring reuse readiness for each topic area within each level. Inconsistencies for measuring reuse readiness across topic areas within each level also are being addressed to improve capabilities for measurement.

Potential uses of the RRLs are as: metadata for reusable software assets stored in catalogs and repositories such as the recommended RES, as a guide to reusers; an indicator of areas to focus on when creating reusable assets, as a guide to providers; and part of requests for proposals or contracts, asking for a reuse approach or how assets are being made reusable<sup>[38]</sup>. By offering a simple way of assessing the reusability of software assets, the RRLs can assist reusers in locating and selecting the most suitable assets to meet their reuse needs. In addition, the detailed topic levels of the RRLs can assist providers in making their assets more reusable, thereby achieving a higher overall RRL, by offering guidance on what they can do to improve the reusability of their assets in each of the topic areas. The WG also is working on creating a tool to calculate RRLs, to help simplify the process of assessing the reuse maturity of software, and plans to incorporate it into the RES, which is also under development. This calculator is expected to enable testing of capabilities to assess reuse readiness levels within and across topic areas and to identify those levels and topic areas that require improvements to facilitate measurement.

Table 1 Draft reuse readiness levels

RRL	Summary	Description
1	The software is not reusable.	Little is provided beyond limited source code or pre-compiled, executable binaries. There is no support, contact information, author attribution, or rights specified, the software is not extensible, and there is inadequate or no documentation.
2	Software reuse is not practical.	Some source code, documentation, and contact information are provided, but these are still very limited. Initial testing has been done, but authorship and reuse rights are still unclear. Reuse would be challenging and cost-prohibitive.
3	The software might be reusable by skilled users at substantial effort, cost and risk.	Software has some modularity and standards compliance, intellectual property agreements have been proposed, some support is provided by developers, and detailed installation instructions are available, but rights are unspecified. An expert may be able to reuse the software, but general users would not.
4	The software might be reused by most users with some effort, cost, and risk.	Software and documentation are complete and understandable. Software has been demonstrated in a lab on one or more specific platforms, infrequent patches are available, and intellectual property issues have been negotiated. Reuse is possible, but may be difficult.
5	The software could be reused by most users with reasonable cost and risk.	Software is moderately portable, modular, extendable, and configurable, has low-fidelity standards compliance, a user manual, and has been tested in a lab. An user community exists, but may be a small community of experts. Authorship and rights are not specified.
6	The software can be reused by most users although there may be some cost and risk.	Software has been designed for extensibility, modularity, and portability, but software and documentation may still have limited applicability. Tutorials are available, and the software has been demonstrated in a relevant environment. Intellectual property statements have been drafted, but authorship and rights have not been formalized.
7	The software can be reused by most users with minimum cost and risk.	Software is highly portable and modular, has high-fidelity standards compliance, provides auto-build installation, and has been tested in a relevant environment. Support is developer-organized, and an interface guide is available. Software and documentation are applicable for most systems.
8	The software has been reused by multiple users.	Software has been shown to be extensible, and has been qualified through test and demonstration. An extension guide and organization-provided support are available. Intellectual property is reviewed in the product before release, and authorship and rights are specified.
9	The software is being reused by many classes of users over a wide range of systems.	Software is fully portable and modular, with all appropriate documentation and standards compliance, encapsulated packaging, a GUI installer, and a large support community that provides patches. Software has been tested and validated through successful use of application output. Complete and clear attribution and permissions for implementation by various user levels are available.

## 6 Conclusion

NASA's Earth Science Data Systems (ESDS) Software Reuse Working Group (WG) is involved in a variety of activities to encourage and support the reuse of software in the Earth science community. The development and maintenance of the portal web site<sup>[5]</sup> is a major education and public outreach ac-

tivity and the primary way the WG communicates relevant news, events, guidelines, etc on software reuse to the community. Work on the recommended Reuse Enablement System (RES) is an example of a support/enablement activity, since it is designed to provide tools and mechanisms to enable reuse by providing the community with access to reusable

software assets within the Earth science domain. The RES is a high priority for the WG, as surveys conducted in 2004 and 2005 showed that having a catalog/repository for reusable Earth science software would be one of the best ways to increase the amount of software reuse within the community<sup>[22]</sup>. The WG is currently developing a prototype RES for internal NASA use and plans to make it available to the public if public access is recommended as a result of its formal evaluation. The development of Reuse Readiness Levels (RRLs) is another support/enabling activity that also contributes to education and public outreach. The ability to assess the reuse maturity of software will provide users with valuable information on how ready the software is to be reused and offer a measure for determining how much modification would be required for the software to meet their needs. It also serves as a guide for software developers by offering information about areas important to software reuse, helping to guide them in developing those areas to higher levels of maturity. In addition to these activities, the WG is also involved in recommending changes to relevant policies to increase opportunities for reuse and assisting others in reuse implementation projects that will result in the publication or use of a reusable component. An example of how the WG has helped others reuse a component is the reuse of the software reuse portal web site design to help create web sites for other ES/DS working groups<sup>[11]</sup>.

The WG's future activities include: continuing development of the RES, with the eventual goal of opening it to the Earth science community; continuing development of the RRLs, with possible applications as noted in Section 5; continuing development and maintenance of the portal web site for education and public outreach; working to facilitate

NASA's software release process, to understand the way large and small software components are handled by the process, and to lower barriers for certain types of software if possible; continuing to develop a peer-recognition award to encourage software reuse; and continuing to promote software reuse through publications in journals and presentations at conferences. Through activities such as these, the WG encourages and supports software reuse in order to help the community of Earth science software developers and other science software developers to reduce costs, increase efficiency, and ensure the reliability of their software products.

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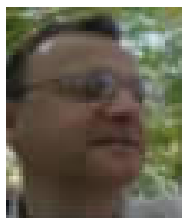
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