LANDSAT
DYNAMIC SURFACE WATER EXTENT (DSWE)
ALGORITHM DESCRIPTION DOCUMENT (ADD)

Version 1.0
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Executive Summary

This U.S. Geological Survey (USGS) Dynamic Surface Water Extent (DSWE) Algorithm Description Document (ADD) defines the algorithms used for the creation of DSWE data products at the USGS Earth Resources Observation and Science (EROS) Center.

This document is under Land Satellites Data System (LSDS) Configuration Control Board (CCB) control. Please submit changes to this document, as well as supportive material justifying the proposed changes, via Change Request (CR) to the LSDS CCB Process and Change Management Tool.
### Document History

<table>
<thead>
<tr>
<th>Document Number</th>
<th>Document Version</th>
<th>Publication Date</th>
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</tr>
</thead>
<tbody>
<tr>
<td>LSDS-1325</td>
<td>Version 1.0</td>
<td>March 2018</td>
<td>CR 14104</td>
</tr>
</tbody>
</table>
Section 1  Introduction

1.1 Background
The Dynamic Surface Water Extent (DSWE) Level 3 algorithm produces image files that represent surface water inundation for each pixel in a Landsat scene. This algorithm was created at the U.S. Geological Survey (USGS) Eastern Geographic Science Center, in cooperation with USGS Earth Resources Observation and Science (EROS) Software Engineers.

1.2 Purpose and Scope
The primary purpose of this document is to provide technical details and information on the creation and how the DSWE algorithm works.

1.3 Document Organization
This document contains the following sections:

- Section 1 introduces DSWE.
- Section 2 provides technical details on the inputs and outputs of DSWE.
- Section 3 provides details on the DSWE algorithm procedures.
- Appendix A provides information specific to the DSWE algorithm auxiliary inputs.
- The References section contains a list of reference documents and supporting webpages.
Section 2  Dynamic Surface Water Extent Algorithm Details

2.1 Dynamic Surface Water Extent Details

The DSWE algorithm is designed to detect water in areas with vegetation over the water. The DSWE algorithm is currently being applied to scenes in the U.S., but is designed to be applicable worldwide.

The algorithm processes both Landsat 4-5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper Plus (ETM+) and Landsat 8 Operational Land Imager (OLI) products.

The DSWE algorithm involves the following steps:

1. Pre-process the input elevation data to produce a percent slope band.
2. Pre-process the input elevation data to produce a hillshade band.
3. Apply several tests to detect water.
4. Recode the initial test results to categories that indicate the likelihood of water.
5. Update the recoded values based on Quality Assurance (QA) values and thresholds.
6. Create a mask band.

2.2 Dynamic Surface Water Extent Inputs

The DSWE algorithm requires the following inputs:

- Landsat Level 2 pixel QA mask
- Landsat Surface reflectance
- Elevation band

2.3 Dynamic Surface Water Extent Outputs

The DSWE procedure creates the following bands:

- Interpreted band with each pixel assigned to a water category: unsigned 8-bit integers
- Bitmapped mask band indicating why each masked pixel is masked: unsigned 8-bit integers
- Interpreted and filtered band containing interpreted results with masking: unsigned 8-bit integers
- Diagnostic band containing results of initial water detection tests (optional): 16-bit integer
- Percent slope (16-bit integer) and hillshade (8-bit integer) intermediate results (optional)
Section 3  Dynamic Surface Water Extent Algorithm
Procedure

The DSWE algorithm procedure contains six steps and are defined in the following sections (these steps are listed in Section 2.1).

3.1 Get Arguments
The DSWE algorithm is controlled by several thresholds (tolerance values), as well as several options. Default values are used; however, these can be overridden with user selections. The default values for Landsat 4, Landsat 5, and Landsat 7 are different than the values for Landsat 8, although currently all default values are the same for the satellites.

Thresholds

- Wigt: Modified Normalized Difference Wetness Index (MNDWI) Threshold
- Awgt: Automated Water Extent Shadow Threshold
- pswt_1_mndwi: Partial Surface Water Test-1 MNDWI Threshold
- pswt_1_nir: Partial Surface Water Test-1 NIR Threshold
- pswt_1_swir1: Partial Surface Water Test-1 SWIR1 Threshold
- pswt_1_ndvi: Partial Surface Water Test-1 NDVI Threshold
- pswt_2_mndwi: Partial Surface Water Test-2 MNDWI Threshold
- pswt_2_blue: Partial Surface Water Test-2 Blue Threshold
- pswt_2_nir: Partial Surface Water Test-2 NIR Threshold
- pswt_2_swir1: Partial Surface Water Test-2 SWIR1 Threshold
- pswt_2_swir2: Partial Surface Water Test-2 SWIR2 Threshold
- percent_slope_high: Slope tolerance for high confidence water. If the percent slope is greater than or equal to this value and the initial tests indicate that the pixel is high confidence water, the pixel is masked.
- percent_slope_moderate: Slope tolerance for moderate confidence water. If the percent slope is greater than or equal to this value and the initial tests indicate that the pixel is moderate confidence water, the pixel is masked.
- percent_slope_wetland: Slope confidence for potential wetland. If the percent slope is greater than or equal to this value and the initial tests indicate that the pixel is potential wetland, the pixel is masked.
- percent_slope_low: Slope tolerance for low confidence water or wetland. If the percent slope is greater than or equal to this value and the initial tests indicate that the pixel is low confidence water or wetland, the pixel is masked.
- Hillshade: Hillshade tolerance value. This should fall within the hillshade range (0-255). If the hillshade value for a pixel is above this threshold, the pixel is masked.
Options

- include_tests: If set, create a diagnostic test file. See Section 3.4. The diagnostic tests are always performed by the algorithm. This option only controls whether the results of the diagnostic tests are saved in a file.
- include_ps: If set, create a percent slope file. See Section 3.2. The percent slope information is always created and used by the algorithm. This option only controls whether the percent slope information is saved in a file.
- include_hs: If set, create a hillshade (shaded relief) file. See Section 3.3. The hillshade information is always created and used by the algorithm. This option only controls whether the hillshade information is saved in a file.
- use_zeven_thorne: Two algorithms are available for the slope algorithm, Horn’s slope algorithm, and Zevenbergen and Thorne’s slope algorithm. If this option is set, the Zevenbergen and Thorne’s slope algorithm is used. The default algorithm (used for official evaluation of DSWE) is the Horn algorithm.
- use_toa: If set, Top of Atmosphere (TOA) reflectance input is used. The default input is Surface Reflectance. This option is not supported for producing official DSWE products. DSWE has only been evaluated with Surface Reflectance input. Also, the default threshold parameters are tailored to Surface Reflectance.
- Verbose: If set, more detailed intermediate messages are printed.
- Version: Displays the DSWE application version number.

3.2 Percent Slope

The percent slope algorithm uses Digital Elevation Model (DEM) input to produce an image structure representing the percent slope of each pixel, where percent slope 100 represents a 45-degree angle. This structure can optionally be written to a band file.

Input:

1. Elevation band

One of two algorithms can be used to compute the slope: 1) Horn’s slope or 2) Zevenbergen and Thorne’s. Both algorithms take a 3x3 elevation window as input while the percent slope is calculated across the pixels in the DEM. The algorithm does not compute percent slope for the outermost rows and columns because the 3x3 elevation window cannot be created in those cases. Those border locations are expected to be fill and not needed.

Output:

1. Percent slope band, optionally written to disk.
3.3 Hillshade
The hillshade algorithm uses DEM input to produce an image structure representing the extent of terrain-produced shadow for each pixel. Sun elevation and azimuth from metadata are also used to determine the source location of light for casting the shadows. The hillshade structure can optionally be written to a band file.

Input:
1. Elevation band
2. Sun elevation and azimuth

The algorithm uses Horn's slope algorithm to calculate slope. Then aspect and finally shaded relief are calculated. The algorithm takes a 3x3 elevation window as input while shaded relief is calculated across the pixels in the DEM. The algorithm does not compute relief for the outermost rows and columns because the 3x3 elevation window cannot be created in those cases. Those border locations are expected to be fill and not needed. The shade values for each pixel are first calculated in the range 0.0...1.0, and are then scaled to a 1...255 range and converted to integer.

Output:
1. Hillshade (shaded relief) band, optionally written to disk.

3.4 Diagnostic Tests
The diagnostic tests phase performs several tests on the input bands.

Input:
1. Unscaled Surface Reflectance bands (an option to use unscaled TOA Reflectance bands is available but not supported for official DSWE products.)
   - Blue band
   - Green band
   - Red band
   - NIR band
   - SWIR1 band
   - SWIR2 band

The following indexes are calculated for each non-fill pixel based on the input bands:

1. Modified Normalized Difference Wetness Index (MNDWI) = (green – SWIR1)/(green + SWIR1)
2. Multi-band Spectral Relationship Visible (MBSRV) = green + red
3. Multi-band Spectral Relationship Near-Infrared (MBSRN) = NIR + SWIR1
4. Automated Water Extent Shadow (AWESH) = blue + (2.5 * green) – (1.5 * MBSRN) – (0.25 * SWIR2)

5. Normalized Difference Vegetation Index (NDVI) = (NIR – red) / (NIR + red)

Five diagnostic tests are then performed for each pixel using these indexes and several threshold values. The result of each test is assigned to a decimal place (1, 10, 100, etc.).

**Test 1:** Compare MNDWI to the wigt Wetness Index threshold, where the threshold ranges from 0.0 to 2.0 and is defaulted to a value of 0.0124.

```java
if (mndwi > wigt) set the ones digit  (Example 00001)
```

**Test 2:** Compare the MBSRV and MBSRN values to each other.

```java
if (mbsrv > mbsrn) set the tens digit  (Example 00010)
```

**Test 3:** Compare AWESH to the awgt Automated Water Extent Shadow threshold, where the threshold ranges from -2.0 to 2.0 and is defaulted to a value of 0.0.

```java
if (awesh > awgt) set the hundreds digit  (Example 00100)
```

**Test 4:** Compare the MNDWI and NDVI along with the NIR and SWIR1 bands to the following thresholds.

- Partial Surface Water Test-1 MNDWI (pswt_1_mndwi) threshold, where the threshold ranges from -2.0 to 2.0 and is defaulted to a value of -0.44.
- Partial Surface Water Test-1 SWIR1 (pswt_1_swir1) threshold, where the threshold ranges from 0 to data maximum and is defaulted to a value of 900.
- Partial Surface Water Test-1 NIR (pswt_1_nir) threshold, where the threshold ranges from 0 to data maximum and is defaulted to a value of 1500.
- Partial Surface Water Test-1 NDVI (pswt_1_ndvi) threshold, where the threshold ranges from 0 to 2.0 and is defaulted to a value of 0.7.

```java
if (mndwi > pswt_1_mndwi && SWIR1 < pswt1_1_swir1
    && NIR < pswt_1_nir
    && NDVI < pswt_1_ndvi)
    set the thousands digit  (Example 01000)
```

**Test 5:** Compare the MNDWI along with the Blue, NIR, SWIR1, and SWIR2 bands to the following thresholds.

- Partial Surface Water Test-2 MNDWI (pswt_2_mndwi) threshold, where the threshold ranges from -2.0 to 2.0 and is defaulted to a value of -0.5.
• Partial Surface Water Test-2 Blue (pswt_2_blue) threshold, where the threshold ranges from 0 to data maximum and is defaulted to a value of 1000.
• Partial Surface Water Test-2 NIR (pswt_2_nir) threshold, where the threshold ranges from 0 to data maximum and is defaulted to a value of 2500.
• Partial Surface Water Test-2 SWIR1 (pswt_2_swir1) threshold, where the threshold ranges from 0 to data maximum and is defaulted to a value of 3000.
• Partial Surface Water Test-2 SWIR2 (pswt_2_swir2) threshold, where the threshold ranges from 0 to data maximum and is defaulted to a value of 1000.

```java
if (mndwi > pswt_2_mndwi
    && Blue < pswt_2_blue
    && SWIR1 < pswt_2_swir1
    && SWIR2 < pswt_2_swir2
    && NIR < pswt_2_nir)
set the ten-thousands digit (Example 10000)
```

**Output:**

1. Diagnostic test band, optionally written to disk.

### 3.5 Recode to Interpreted DSWE

The diagnostic tests band gives a five-digit decimal output where each digit is either 0 or 1, representing the results of the five diagnostic tests. The results of the five tests are recoded to an interpreted class DSWE band.

**Input:**
Diagnostic tests band

The interpreted class DSWE band has the following possible values:

<table>
<thead>
<tr>
<th>Value</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Not Water</td>
</tr>
<tr>
<td>1</td>
<td>Water - High Confidence</td>
</tr>
<tr>
<td>2</td>
<td>Water - Moderate Confidence</td>
</tr>
<tr>
<td>3</td>
<td>Potential Wetland</td>
</tr>
<tr>
<td>4</td>
<td>Low Confidence Water or Wetland</td>
</tr>
<tr>
<td>255</td>
<td>Fill (no data)</td>
</tr>
</tbody>
</table>

The following translation is performed to recode from the diagnostic test values to the interpreted class values:

<table>
<thead>
<tr>
<th>Diagnostic Test Value</th>
<th>Interpreted Class Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>00000</td>
<td>0 (Not Water)</td>
</tr>
<tr>
<td>00001</td>
<td>0</td>
</tr>
<tr>
<td>00010</td>
<td>0</td>
</tr>
<tr>
<td>00100</td>
<td>0</td>
</tr>
<tr>
<td>01000</td>
<td>0</td>
</tr>
</tbody>
</table>
01111 : 1 (Water - High Confidence)
10111 : 1
11011 : 1
11101 : 1
11110 : 1
11111 : 1

00111 : 2 (Water - Moderate Confidence)
01011 : 2
01101 : 2
01110 : 2
10011 : 2
10101 : 2
10110 : 2
11001 : 2
11010 : 2
11100 : 2

11000 : 3 (Potential Wetland)

00011 : 4 (Low Confidence Water or Wetland)
00101 : 4
00110 : 4
01001 : 4
01010 : 4
01100 : 4
10000 : 4
10001 : 4
10010 : 4
10100 : 4
255 : 255 (Fill)

The interpreted band is written to disk.

Output:
Interpreted DSWE band

3.6 Percent Slope, Hillshade, Cloud, Cloud Shadow, and Snow (PSHSCCSS)
This step starts with the interpreted band, and checks the percent slope, hillshade, and pixel QA bands. It uses those bands to filter the interpreted band results.

Input:
1. Interpreted band
2. Pixel QA band
3. Percent slope band
4. Hillshade band
Percent slope is used to remove locations where the terrain is too sloped to hold water. Any locations that are too sloped are recoded to a value of 0. Similarly, any locations where the terrain is too shaded are recoded to a value of 0. The checks use the hillshade threshold and the four percent slope thresholds.

**Test 1:** Perform the following checks by comparing the Percent Slope band to the Percent Slope thresholds. Pixels that fail the test are set to 0 (Not Water).

if (percent-slope >= percent_slope_high) and
   the Interpreted DSWE is High Confidence Water (1)
   set the filtered Interpreted DSWE to a recoded value of 0
otherwise set it to Interpreted DSWE
if (percent-slope >= percent_slope_moderate) and
   the Interpreted DSWE is Moderate Confidence Water (2)
   set the filtered Interpreted DSWE to a recoded value of 0
otherwise set it to Interpreted DSWE
if (percent-slope >= percent_slope_wetland) and
   the Interpreted DSWE is Potential Wetland (3)
   set the filtered Interpreted DSWE to a recoded value of 0
otherwise set it to Interpreted DSWE
if (percent-slope >= percent_slope_low) and
   the Interpreted DSWE is Low Confidence Water or Wetland (4)
   set the filtered Interpreted DSWE to a recoded value of 0
otherwise set it to Interpreted DSWE

**Test 2:** Perform the following test by comparing the Hillshade band to the Hillshade threshold. Pixels that fail the test are set to 0 (Not Water):

if (hillshade <= hillshade threshold)
   set the filtered Interpreted DSWE to a recoded value of 0
otherwise set it to Interpreted DSWE

**Test 3:** Compare the Pixel QA (quality/mask) band to the Cloud, Snow, and Cloud Shadow values. Pixels that fail the check are set to 9 (Cloud, Cloud Shadow, or Snow):

if (the Pixel QA cloud, cloud shadow, and/or snow bit is set)
   set the filtered Interpreted DSWE to a recoded value of 9
otherwise leave it alone

The band is written to disk. Intermediate bands are optionally written to disk.

**Output:**

1. PSHSCCSS filtered interpreted band
2. Hillshade band
3. Percent slope band, scaled and converted to 16-bit integer
3.7 Mask
The DSWE mask band identifies where and why pixels are filtered in the PSHSCCSS product.

Input:

1. Interpreted band
2. Pixel QA band
3. Percent slope band
4. Hillshade band

The mask band is a bitmapped band where the bits have the following values:

- 0 - Cloud shadow mask applied
- 1 - Snow mask applied
- 2 - Cloud mask applied
- 3 - Percent slope mask applied
- 4 - Hillshade mask applied

Multiple mask reasons can apply for each pixel in the mask band. For example, a pixel masked for cloud shadow, percent slope, and hillshade have a value of 25 (2^0 + 2^3 + 2^4 = 1 + 8 + 16 = 25).

The mask band is created with the following steps:

1. The mask is initialized to 0, and the contribution of the pixel QA mask values is added:

   if (pixel QA cloud shadow bit is set)
   set mask shadow bit (0)
   if (pixel QA snow bit is set)
   set mask snow bit (1)
   if (pixel QA cloud bit is set)
   set mask cloud bit (2)

2. The contribution of the percent slope mask values is added:

   if (any percent slope test caused Interpreted DSWE to be recoded to 0)
   set mask percent slope bit (3)
3. The contribution of the hillshade mask values is added:

    if (the hillshade test caused Interpreted DSWE to be recoded to 0

        set mask hillshade bit (4)

The percent slope and hillshade mask steps are performed during the test1 and test2 steps during the PSHSCCSS procedure to avoid repeating the checks.

The mask band is written to disk.

**Output:**

1. Mask band
Appendix A  DSWE Algorithm Static Input

DSWE processing is based on the following input to the algorithm, which needs to be processed and made available prior to running the DSWE algorithm:

- Elevation dataset

The USGS EROS Science Processing Architecture (ESPA) Elevation Project is used to generate the elevation dataset based on the extent of the Landsat scene as documented in the scene metadata.
References

Please see https://landsat.usgs.gov/glossary-and-acronyms for a list of acronyms.
