Digital Representation of Oil and Natural Gas Well Pad Scars in Southwest Wyoming

Data Series 800

U.S. Department of the Interior
U.S. Geological Survey

COVER. Drill pad of gas wells in southwestern Wyoming (photo by Lori Baer).

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Contents

Figure

Tables

Conversion Factors

SI to Inch/Pound

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
meter (m)	1.094	yard (yd)
	Area	
square meter (m^2)	0.0002471	acre
hectare (ha)	2.471	acre
square hectometer (hm^2)	2.471	acre
square kilometer (km^2)	247.1	acre
square centimeter (cm^2)	0.001076	square foot (ft^2)
square meter (m^2)	10.76	square foot (ft^2)
square centimeter (cm^2)	0.1550	square inch (ft^2)
square hectometer (hm^2)	0.003861	section (640 acres or 1 square mile)
hectare (ha)	0.003861	square mile (mi^2)
square kilometer (km^2)	0.3861	square mile (mi^2)

Horizontal coordinate information is referenced to the Universal Transverse Mercator (UTM).

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Abstract

The recent proliferation of oil and natural gas energy development in southwest Wyoming has stimulated the need to understand wildlife responses to this development. Central to many wildlife assessments is the use of geospatial methods that rely on digital representation of energy infrastructure. Surface disturbance of the well pad scars associated with oil and natural gas extraction has been an important but unavailable infrastructure layer. To provide a digital baseline of this surface disturbance, we extracted visible oil and gas well pad scars from 1-meter National Agriculture Imagery Program imagery (NAIP) acquired in 2009 for a 7.7 million-hectare region of southwest Wyoming. Scars include the pad area where wellheads, pumps, and storage facilities reside, and the surrounding area that was scraped and denuded of vegetation during the establishment of the pad. Scars containing tanks, compressors, and the storage of oil and gas related equipment, and produced-water ponds were also collected on occasion. Our extraction method was a two-step process starting with automated extraction followed by manual inspection and clean up. We used available well-point information to guide manual clean up and to derive estimates of year of origin and duration of activity on a pad scar. We also derived estimates of the proportion of non-vegetated area on a scar using a Normalized Difference Vegetation Index derived using 1-meter NAIP imagery. We extracted 16,973 pad scars of which 15,318 were oil and gas well pads. Digital representation of pad scars along with time-stamps of activity and estimates of non-vegetated area provides important baseline (circa 2009) data for assessments of wildlife responses, land-use trends, and disturbance-mediated pattern assessments.

Introduction

Southwest Wyoming contains one of the nation's largest natural gas reserves (U.S. Department of the Interior, Agriculture, and Energy, 2006), as well as high-quality wildlife habitat (Sawyer and others, 2005), and a significant portion of the remaining intact sagebrush steppe in the country (Connelly and others, 2004). For these reasons, a research effort known as the Wyoming Landscape Conservation Initiative (WLCI) was initiated to provide science-based guidance for assessing and enhancing the aquatic and terrestrial ecosystems of southwest Wyoming while facilitating responsible energy development (Bowen and others, 2009). Geospatial assessments of energy effects on wildlife that rely on digital representation of energy infrastructure are a concerted portion of WLCI research efforts. Geospatial layers for roads and other human-mediated disturbances exist for the WLCI study area, but digital representation of oil and gas pad scars has been limited despite the importance of this surface-disturbance feature. Our goal was to provide a baseline (circa 2009) digital representation of oil and gas well pad scars in the WLCI study area for use in wildlife habitat assessments, and more generally, in assessments of land-use trends.

A previous effort examined the utility of object-extraction software for rapid extraction of oil and gas well pad scars from satellite imagery of varying resolutions (Germaine and others, 2012). Results of that study, however, illustrated the difficulty in using totally automated procedures for the extraction of surface disturbances in an environment typified by sparse vegetation and large areas of naturally occurring bareground. Moreover, on-screen digitizing of imagery was found to be the most accurate. To expedite extraction, we developed a hybrid approach consisting of customized automated procedures to help identify and extract oil and gas well pad scars, followed by manual clean-up and on-screen digitizing of omitted pad scars.

Purpose and Scope

The purpose of this report is to publish the geospatial oil and gas pad scar data for southwest Wyoming and to document the methods used to extract pad scars from 1-meter National Agriculture Imagery Program imagery (NAIP). Pad scars include the disturbed surface area resulting from the drilling of oil and gas wells and from subsequent pumping and storage of extracted fluid minerals and produced water. Typically, pad scars consist of a core area of disturbed soil around wellheads and associated pumping and storage facilities. Water extracted from drilling and well operation also may be stored in small ponds located within this core area. Re-vegetation of the core area often is limited due to continuous vehicular and foot traffic during the operation of oil and gas wells. The area around the core tends to be scraped and denuded of vegetation during the construction of a pad. Re-vegetation of this surrounding area varies with the restoration regulations in-place during the development of the pad and the age of the pad. The core and surrounding scraped area is collectively considered a pad scar. Visible oil and gas well pad scars from current and past operations were included in this data set. Although not a primary goal, scarred areas that lacked wellheads but contained tanks, compressors, equipment storage, and large ponds of produced water related to oil and gas development were ocassionally extracted. Scars are labeled to identify the type (oil and gas well pad, storage, produced-water pond). Data are available from: *http://dx.doi/org/10.3133/ds800*.

Study Area

The WLCI encompasses a 7.7 million-hectare region of southwest Wyoming (fig. 1). Oil extraction in this region started in the early 1900’s. In more recent times, natural gas development has dominated.

Methods

Pad Scar Extraction

We used a two-step process to produce a digital representation of primarily oil and gas well pad scars from NAIP imagery. We first developed automated procedures to extract pad scars from 4-band (red, green, blue, near infrared), 1-meter NAIP imagery acquired in the summer of 2009 (total of 2,200 images). Classification Tree (CT) models are commonly used to map and classify features from imagery, such as vegetation types (McDermid and Smith, 2008), soils (Garman and others, 2010), and urban areas (Matikainen and Karila, 2011). Using digitized pads and other infrastructure features from a high-intensity energy field as training data and corresponding NAIP imagery, we developed a CT model that predicted surface-disturbance classes (table 1). For each NAIP image, the CT model assigned each pixel to a disturbance class. Pond and pad scar classes then were combined to form patches. Subsequent processing relied on the tendency for pad scars to have shapes different from other surface disturbance features and naturally occurring bareground patches. Since pads tend to be oval to rectangular in shape, we eliminated elongated and irregularly shaped features which tended to be natural patches of very sparse vegetation or bareground and roads.

The result of this process was the extraction of patches that were likely pad scars. The coordinates of oil and gas wells from Biewick (2011), referred to as well points (location of the drill hole), were used to identify patches that overlapped with well points. Patches with overlapping well points were coded to indicate a high probability of being actual pad scars. Other patches were coded as low probability of being pad scars. The output from this first step was an Esri grid file of probable pad scars that was converted to polygons for input to the next step. The overall intent of our extraction procedure was to provide an initial representation of possible pad scars to facilitate the subsequent manual editing procedure; the intent was not to provide highly accurate representation of scars. Previous studies (Germaine and others, 2012) and initial assessments of our classification efficiency demonstrated limited accuracy with automated extraction methods. Our extraction procedure simply provided a baseline for the manual evaluation of pad scars.

The second step in producing a digitial representation consisted of verifying and correcting the results from the automated procedure. Well points from Biewick (2011) and the Wyoming Oil and Gas Conservation Commission (2009) Application for Permit to Drill (WOGCC APDs) served as reference points for locating pad scars in NAIP imagery. Well points and extracted pad scar polygons were overlaid on NAIP imagery, and each image was scanned for pad-scar accuracy (omission, commission, and completeness). Well points with no visible associated scar were checked for positional accuracy using the WOGCC APDs data set. If the well point was located correctly according to the Public Land Survey System (PLSS) information, the surrounding area was scanned again to insure scars were not missed. There were instances where the well points were appropriately located but a scar was not visible due to re-growth of vegetation. Where extracted pad scars corresponded to scars in the image, the shape and size of extracted scars were evaluated and adjusted, if necessary, to match the imagery. Misclassified scars were eliminated. Omitted pad scars were added by on-screen digitizing. Manual edits were completed using the tools of the Editor Toolbar in ArcMap™ Desktop (versions 9.3 and 10). For consistency, only five individuals were involved in editing.

After the digital representation of pad scars was finalized, pad scars were uniquely numbered for identification purposes (#1, table 2), and scar size was derived and recorded (#2, table 2). The WLCI study area spans Universal Transverse Mercator coordinate system (UTM) zones 12 and 13. The UTM zone of pad scars was recorded (#3, table 2) and used to derive pad scar shapefiles for each UTM zone. Typically, an entire pad scar could be represented by a single polygon. However, some large scars were dissected by roads. To avoid including the road area, the scar area on each side of a road was represented by separate polygons, with one typically being much larger than the other and containing one or more wellhead locations. Since all pad scar polygons were uniquely numbered, an attribute field was used to identify separate polygons representing a single pad scar (#6, table 2).

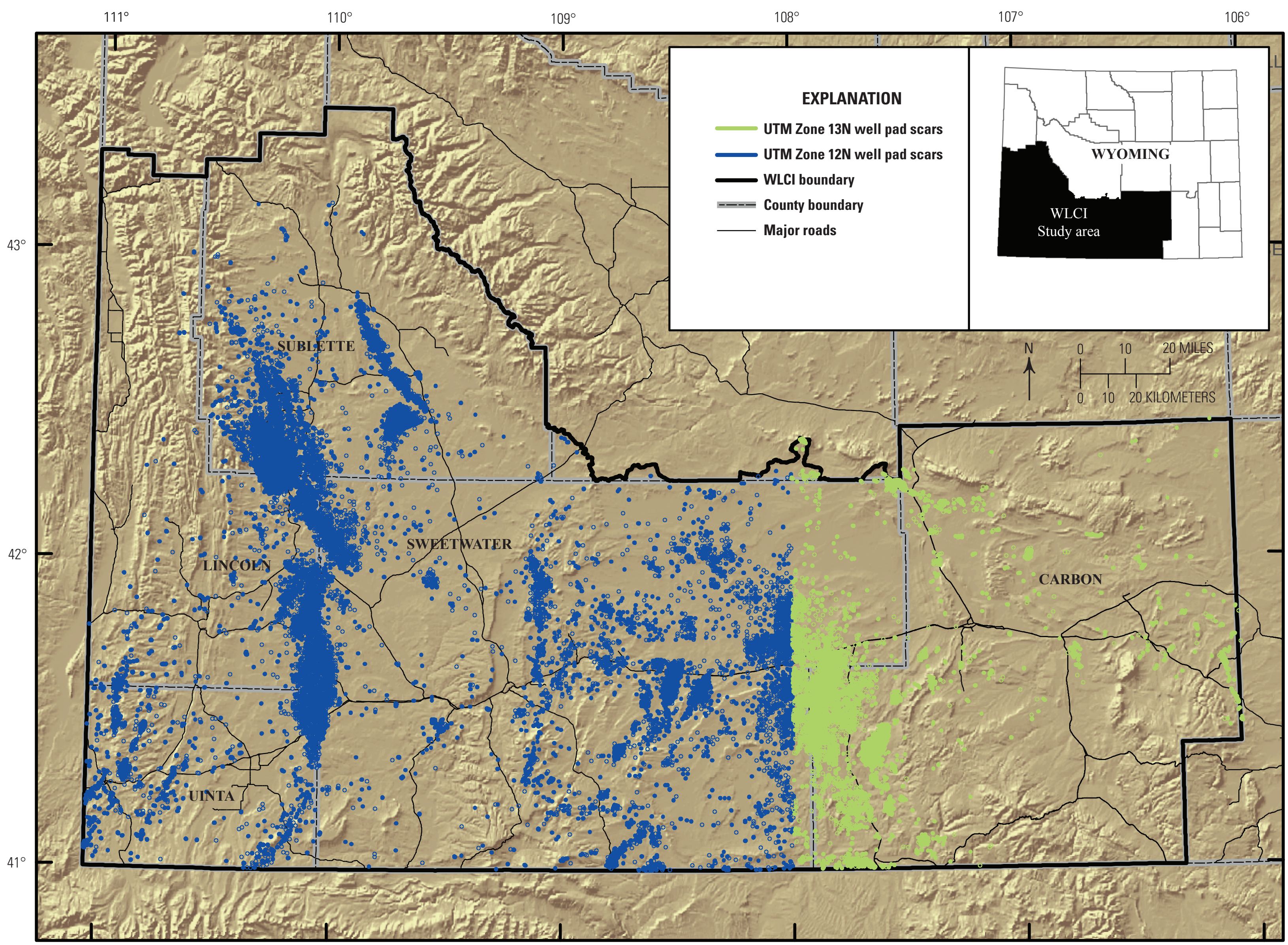

Figure 1. The Wyoming Landscape Conservation Initiative study area and the locations of oil and gas well pad scars provided in this report.

Table 1. The classification tree, in the form of classification rules, used to extract oil and gas well pad scars from 1-meter NAIP imagery. Band3 and Band4 are the Digital Number of bands 3 and 4, respectively. STDT4 is the standard deviation of Band 4 values within a 9 × 9-meter window centered on a focal cell. Pond is produced water that is stored on a pad scar. Other is surface disturbances other than an oil and gas well pad scar.

IF **Band4** <109			→ *Pond*	
ELSE				
	IF **Band3** ≥ 142			
		IF **STDT4** ≥ 36	→ *Pond*	
		ELSE		→ *Pad scar*
	ELSE			→ *Other*

Our primary objective was to provide digital representation of visible oil and gas well pad scars, but ancillary scars were also acquired. There were instances where large scars associated with the storage of holding tanks, compressors, and other oil and gas equipment, and consisting solely of produced-water ponds were extracted in the automated procedure or were incidentally collected in the manual clean-up process. These scars were retained in the final shapefiles. However, since these types of scars were not the primary target, we do not claim to have extracted all oil and gas storage and produced-water scars in the study area. A pad-scar type attribute was used to identify the different types of extracted scars: oil and gas well pad, storage, and produced-water pond (#5, table 2).

Time Period of Activity

The time period of active use of a pad scar is important in retrospective assessments of human-wildlife interactions, and more generally, in temporal assessments of land-use patterns. To estimate when a pad scar was created and the last year of activity on a pad, we used well-permit information, which included drilling dates, well status, and dates of status reports. The primary information source was Biewick (2011), who calculated start and stop years of wells from 2010 WOGCC data. In initial assessments, we discovered pad scars associated only with permitted wells that were never drilled. That is, all permits for the well location had a status of Expired Permit (EP), but it was clear from the NAIP imagery that these areas had been scraped in preparation for drilling. Because EP information was not used in Biewick (2011), we generated a newer version of start and stop years for all well points using the WOGCC APDs data set and status information from Wyoming Oil Gas Conservation Commission (2012) Well Data, which included EP wells. We followed procedures in Biewick (2011) where the permit history of a well point was scrutinized to determine the spud date (year when drilled), and the year of the most recent status report and the corresponding status (e.g., permanently abandoned, producing gas). Additionally, we determined if only EPs were associated with a well location. If so, we assumed the year of the first EP was the origin year of an associated pad scar.

The time period of activity and number of well points associated with a pad scar were derived using the following described procedures. These procedures were performed separately with Biewick's (2011) data and the well point summary we derived. We used the results from our summary information in situations where well points overlapped a pad scar or were closer to a pad scar compared to results with Biewick (2011), or where only EP wells occurred on or near a pad scar. Otherwise, results using Biewick (2011) were recorded. We recorded the source of information used to derive well-point numbers and activity years (#21, table 2).

Duration of Activity Procedure

We first performed a spatial join of the well points and the pad scars with the "is closest to it" option in ArcMap™. This assigned each well point to the closest pad scar and recorded the distance from the point to the scar. For each pad scar, we derived the number of overlapping well points (#7, table 2), and the minimum start (#8, table 2) and maximum stop year (#9, table 2) of these points. If only well points with EPs overlapped a pad scar, the year of the earliest permit was assigned to the start and stop year of the pad scar, and the use of only EP information was noted (#10, table 2). There were numerous well points that were near but not on a pad scar, either due to inaccurate georegistration or mis-interpretation of the bounds of a pad scar. Based on visual inspection, well points within 100 meters of a pad scar tended not to be associated with another visible pad scar. Thus, we assumed these well points were likely associated with the pad scar less than or equal to 100 meters away.

We recorded the number (#11, table 2), the maximum distance from a pad scar (#12, table 2), the minimum start (#13, table 2), and the maximum stop year (#14, table 2) of well points within 100 meters of a pad scar. The maximum distance of well points was recorded to aid in assessing the reliability of associating start and stop years from non-overlapping well points to a pad scar. If there were no well points overlapping a pad scar and only wells with EPs were within 100 meters of a scar, then the year of the first permit was used as the start and stop year for the scar, and the use of only EP information for this distance interval was noted (#15, table 2). Where no well points occurred less than or equal to 100 meters of a scar, the number (#16, table 2), maximum distance from the scar (#17, table 2), and the minimum start (#18, table 2) and maximum stop years (#19, table 2) of well points greater than 100 and less than or equal to 200 meters from a scar were recorded. Information from well points with EPs was only recorded if there were no other well points less than or equal to 200

Table 2. Attributes of a pad-scar file (EP, Expired Permit; m, meters).

Field number and name	Values	Definition
(1) ID	1–16973	Accession numbering continues across the two shapefiles (starting with 1 in padscar_ utm12).
(2) Area_Ha	>0	Area of scar (hectares).
(3) UTM	12 or 13	UTM zone.
(4) NonVeg	0–1.0	Estimated proportion of a scar that lacks noticeable vegetation.
(5) Type	OG, S, P, POG	Type of scar, where OG, oil and gas well pad; S, tanks, compressors and storage of oil and gas-related equipment; P, produced-water ponds from oil and gas extraction; POG, possible OG but lacks documented well points in the vicinity.
(6) SPAD	≥0	This field is set (>0) for pad scars that appear to be a smaller piece of a large scar but are separated from the larger piece by a road. The value of this field is the ID of the larger portion of the scar.
(7) Pts_scar	≥0	Number of well points overlapping a pad scar.
(8) Start1	≥0	Minimum start year of well points overlapping a pad scar. Set to zero if no points overlap a scar or if year information was not available.
(9) Stop1	≥0	Maximum stop year of well points overlapping a pad scar. Set to zero if no points overlap a scar or if year information was not available.
(10) EP_scar	EP or blank	Set to EP if Pts_scar, Start1, and Stop1 were based on Expired Permit information.
(11) Pts_100m	≥0	Number of well points occurring >0 and ≤100 m from a scar.
(12) MDist100_m	≥0	Maximum distance from the scar of well points included in Pts_100m. Set to zero if Pts_100m = 0.
(13) Start2	≥0	Minimum start year for all well points >0 and ≤100 m from a scar. Set to zero if Pts_100m = 0 or if year information was not available.
(14) Stop2	≥0	Maximum stop year for all well points >0 and ≤100 m from a scar. Set to zero if Pts_100m = 0 or if year information was not available.
(15) EP_100m	EP or blank	Set to EP if Pts_100m, Start2, and Stop2 were based on Expired Permit information.
(16) Pts_200m	≥0	Number of well points occurring >100 and ≤200 m from a scar. Information for this field is not acquired if well points occurred ≤100 m of a scar.
(17) MDist200_m	≥0	Maximum distance from the scar of well points included in Pts_200m. Set to zero if Pts_200m = 0.
(18) Start3	≥0	Minimum start year for all well points >100 and ≤200 m from a scar. Set to zero if Pts_200m = 0 or if year information was not available.
(19) Stop3	≥0	Maximum stop year for all well points >100 and ≤200 m from a scar. Set to zero if Pts_200m = 0 or if year information was not available.
(20) EP_200m	EP or blank	Set to EP if Pts_200m, Start3, and Stop3 were based on Expired Permit information.
(21) D_source	B, G	Source of the activity information (number of well points, and start and stop years); where B = Biewick (2011), G = the well-point summary from this study (see text).
(22) Act_scar	≥0	Number of well points overlapping a scar with a stop year of 2010 and classified as active.
(23) Act_100m	≥0	Number of well points >0 and ≤100 m from a scar with a stop year of 2010 and classified as active.
(24) Act_200m	≥0	Number of well points >100 and ≤200 m from a scar with a stop year of 2010 and classified as active.
(25) Inact_scar	≥0	Number of well points overlapping a scar with a stop year of 2010 and classified as inactive.
(26) Inact_100m	≥0	Number of well points >0 and ≤100 m from a scar with a stop year of 2010 and classified as inactive.
(27) Inact_200m	≥0	Number of well points >100 and ≤200 m from a scar with a stop year of 2010 and classified as inactive.

meters from a scar (#20, table 2). The 200-meter distance threshold was considered a maximum for providing credible information about pad-scar activity whenever closer well points were not available. Start and stop years for pads lacking well points within 200 meters were set to 0 for unknown, and the scar type (#5, table 2) was set to "POG" to indicate a possible oil and gas well pad scar that was not substantiated by having documented well points in proximity.

Because 2010 data were used by Biewick (2011), the maximum stop year recorded in our activity duration assessment was 2010. The most recent status report of a well point provides an indication of active or inactive status. For each pad scar, we recorded the number of well points with a stop year of 2010 that were considered to be active or inactive in each of the three distance intervals (#22-27, table 2). Where status of well points with a stop year of 2010 was not provided, numbers of active and inactive wells (#22-27 in table 2) were set to 0.

Non-vegetated Area

Visible well pad scars in the 2009 NAIP imagery included abandoned and currently used pads, and consequently differed in the amount of vegetation cover and bareground. Estimates of vegetation cover or the lack of cover may be useful in assessments of wildlife habitat, soil erosion, and hydrologic responses. To provide a measure related to ground cover, we developed a relatively rapid method to estimate non-vegetated area for each pad scar. We developed an automated procedure that used the 2009 1-meter NAIP imagery, a road-data layer, and Normalized Difference Vegetation Index (NDVI) values to estimate the proportion of each pad scar that lacked noticeable vegetation (#4, table 2). Unpaved road surfaces served as a reference for determining NDVI values representative of non-vegetated areas. For each image, we generated NDVI values for each 1-meter pixel, overlaid a 1-meter raster representing unpaved roads and derived the distribution of NDVI values for these roads, then overlaid a 1-meter raster of the pad scars. The proportion of a pad scar with NDVI values equal to or less than the 50th percentile of the road NDVI distribution was ascribed as the proportion of non-vegetated area. We assessed different percentile thresholds, but found results using the 50th percentile to have the highest correlation (r = 0.89) with manually derived estimates (on-screen digitizing) of non-vegetated area for 100 randomly selected pad scars.

Results and Discussion

A total of 16,973 pad scars were extracted from the 2200 NAIP images (Quarter Quads) covering the WLCI area (fig. 1). Of these, 15,318 are oil and gas well pad scars, 210 are storage facilities, and 15 are produced-water ponds. There are 1,430 scars that appeared to be oil and gas well pad scars but lacked overlapping and nearby (less than or equal to 200 meters) well points (Type = POG). Pad scars were separated by UTM zone, resulting in two shapefiles – padscar_utm12 and padscar_utm13.

Despite our efforts to extract and accurately delineate the shape of all visible pad scars, it is likely that some extant pads were omitted and the boundaries of some scars are not exact. The ability to discern older pad scars varied among NAIP images due to differences in image brightness and color contrast and the amount of naturally occurring bareground. The ability to delineate exact boundaries of pad scars also varied with the reflectance properties of images, the amount of natural bareground in the vicinity, and scar age. We recommend that a user of these data inspect the quality and accuracy of pad scars for their area of interest to determine necessary enhancements in terms of scar shape and size, and omission of scars. Also, because the vintage of these data is 2009, contemporary applications will require the addition of pad scars since 2009.

We derived estimates of the number of well points and activity duration associated with a pad scar accounting for potential error in well-point locations. Estimates are most reliable when derived from well points overlapping a pad scar. However, summarizing information from well points within 100 meters of a scar may be justified when the maximum distance of points is relatively small (for example, less than or equal to 50 m). Estimates using well points greater than 100 and less than or equal to 200 meters from a pad scar were provided only when closer well points were not available. It is possible that these well points actually correspond to older, reclaimed pad scars no longer visible in NAIP imagery. Thus, estimates from this distance interval should be viewed with caution. Overall, it is up to the user of the data to determine the distance interval(s) that provides the most comprehensive estimate of activity duration and numbers of well points associated with a pad scar.

Our approach to estimating the proportion of a pad scar that is non-vegetated was logical, and relatively accurate compared to a limited number of digitized estimates from 1-meter NAIP imagery. We lacked the resources, however, to perform ground-truthing of estimates. A user of the data is responsible for assessing the applicability of our estimates given their study objectives and is responsible for conducting field verification of these estimates.

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